OCT 0 3 2000 0612 I 49.2:C 44/DRAFT

U.S. Fish & Wildlife Service

The Chinese Mitten Crab Invasion of California:

A Draft National Management Plan for the Genus Eriocheir

2001-001449/NF C

The Chinese Mitten Crab Invasion of California:
A draft National Management Plan for the Genus Eriocheir

Draft
August 2, 1999

Prepared by:
Kim Webb
U.S. Fish and Wildlife Service
4001 North Wilson Way,
Stockton California, 95205

I

The Chinese Mitten Crab Invasion of California: A Draft Management Plan for the Genus *Eriocheir*

Contents **Page**

I. Acknowledgments 1

II. Purpose 2

III. Executive Summary 3

IV. Introduction 5

V. Developing the Management Plan 13

VI. Problem Definition 16

VII. Implementation 19

VIII. Implementation Summary 22

IX. Key to Table Abbreviations 27

X. References 28

Appendices

Appendix A. Overview of the Life History, Distribution, Abundance and Impacts of Chinese mitten crab *Eriocheir sinensis*. Tanya Veldhuizen and Stacy Stanish 29

Appendix B. Summary of Mitten Crab Workshop Recommendations 59

Appendix C. U.S. Bureau of Reclamation Fish Facilities Mitten Crab Management Plan 61

Appendix D. Department of Water Resources Fish Facilities Mitten Crab Management Plan 83

Appendix E. Current Status on the Increasing Numbers of the Chinese Mitten Crab *Eriocheir sinensis* in German Rivers. Stephan Gollasch 89

Appendix F. The Alien Chinese Mitten Crab, Eriocheir sinensis,
in the Thames Catchment. Paul Clark, Philip Rainbow, Roni Robbins,
Brian Smith, William Yeomans, Myles Thomas and Gina Dobson 98

Appendix G. Hudson River Background and Information
Quentin Ross. 106

List of Figures

1. Expansion of the Chinese mitten crab distribution in the San Francisco Bay-Delta
Kathy Hieb, California Department of Fish and Game 9

2. Potential distribution of the Chinese mitten crab in California
Kathy Hieb, California Department of Fish and Game 10

3. Adult Chinese mitten crab catch from the San Francisco Bay Study otter trawl survey, September-May, 1995-1999. Kathy Hieb, California Department of Fish and Game ... 11

4. Chinese mitten crab life cycle
Tanya Veldhuizen, California Department of Water Resources 12

5. Chinese mitten crab Risk Assessment Conceptual Model: Pathways and Effects 16

List of Tables

1. Estimated Values of Selected Delta Fisheries 8

2. Implementation Table 25

Acknowledgments:

I am very grateful to the many individuals and organizations that have contributed their valuable time and resources to the development of this Plan. This has been a cooperative effort which has benefitted from the knowledge and expertise of many talented people from a wide range of interests. Thank you for your interest and assistance.

There are also significant contributions which warrant special acknowledgment:

- Kathy Hieb (California Department of Fish and Game) provided the benefits of her knowledge and expertise as well as extensive assistance with planning and organization.
-Tanya Veldhuizen (California Department of Water Resources) as lead person responsible for the literature search and report along with her assistant, Stacy Stanish.

Special thanks to the co-sponsors of the Chinese Mitten Crab Workshop:

-University of California Cooperative Extension, Davis - Ted Grosholz
-San Francisco Estuary Project - Marcia Brockbank and Joan Patton
-Western Regional Panel on Aquatic Nuisance Species

Also contributing valuable information:

Stephan Gollasch, Institute of Marine Sciences, Germany
Paul Clark, Department of Zoology, Natural History Museum, London
Roni Robbins, School of Biological Sciences, University of London
Greg Ruiz, Smithsonian Environmental Research Center
Interagency Ecological Program Mitten Crab Project Work Team
U.S. Bureau of Reclamation - Lloyd Hess, Brent Bridges and Scott Siegfried

A special thank you to Lee Mecum of California Department of Fish and Game for the cover photograph of *Eriocheir sinensis*.

Coordination Chair,

Kim Webb
U.S. Fish and Wildlife Service

Purpose

The rapidly expanding population of Chinese mitten crab *Eriocheir sinensis* has begun to cause negative impacts in the San Francisco Bay-Delta. In light of the potential distribution in California and to ecosystems well beyond the State of California, and the negative economic and ecological impacts associated with the establishment of mitten crab, the leadership of the National Aquatic Nuisance Species Task Force (ANSTF) asked the U. S. Fish and Wildlife Service (Service) to take the lead in working with the State of California and other interested entities on the development of a draft National Management Plan (Plan) for this genus of crab. Efforts to develop the plan began with the organization of an interagency meeting in September of 1998, a literature search and summary report on the Chinese mitten crab during the winter of 1998, and a workshop held on March 23, 1999. Over 125 people representing a variety of organizations, agencies, industries, individuals and other interested entities (NGOs, scientists, consultants, etc.) met in Sacramento, California for this workshop, which was the culmination of months of discussion and meetings about the realized and potential impacts of this invader. The Plan describes opportunities to prevent spread, detect and monitor populations, reduce the negative impacts and control populations. The Plan will be presented to the ANSTF for consideration at their August 1999 meeting.

The ANSTF is an intergovernmental body established by the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 which authorized the ANSTF to develop control programs for aquatic nuisance species. The information provided in this Plan is intended to assist the ANSTF with the determination of the appropriate response to the mitten crab invasion.

Executive Summary

During the fall of 1998, the San Francisco Estuary experienced the tremendous downstream migration of the introduced Chinese mitten crab. In the short time since it's introduction, this crab has become very abundant and widely distributed throughout the watershed. The increase in population is similar to reports of the German experience with the mitten crab in the 1930s. The adult migration period has negatively impacted the Central Valley water diversion fish salvage facilities, as well as both commercial and recreational fisheries. Mitten crabs also represent a serious threat to levees, agriculture, other water diversion systems and the ecosystem.

The Aquatic Nuisance Species Task Force (ANSTF) has followed the status of the mitten crab invasion of California since early 1998 and has requested the cooperative development of a draft management plan for this genus of crab. The U.S. Fish and Wildlife Service has supported an examination and summary of the literature, a public meeting and a workshop to review available information and develop recommendations for management actions. A summary of these activities is contained in this report to the ANSTF entitled "The Chinese Mitten Crab Invasion of California: A Draft Management Plan for the Genus *Eriocheir*."

The evaluations have concluded that the genus *Eriocheir* poses a significant threat to the economic and environmental resources of several areas of North America and that, unless prompt measures are taken, *Eriocheir* species may establish populations in new areas of the country. The ANSTF is urged to take prompt action to prevent further spread of the crab and to reduce the negative impacts of the existing population. This report presents a draft recommended management plan for the genus *Eriocheir* to be considered for adoption by the ANSTF. Estimated costs and implementing entities are identified for many of the recommended actions, but not all have been identified at this point. It is important to note that we have determined that a vital component of this program will be adaptive management. Currently, we do not have enough information about this crab to implement many actions. As we move forward with projects, we will incorporate the results of our findings into our planning. To enhance the success of the program, a certain amount of flexibility to adopt our program is necessary in order that we can take advantage of the generation timely information.

The draft management plan consists of four primary objectives:
a) Prevent spread
b) Detect new populations and monitor existing populations
c) Reduce negative impacts
d) Develop strategies and methods for population control

We strongly urge the ANSTF to begin implementation of the management plan early in FY00 and that the remaining elements of the plan be implemented as quickly as possible. At present, there is an opportunity to prevent the type of invasion we have witnessed in California from occurring in the Columbia River, the Mississippi River, and the Hudson River. If action is not taken quickly, future control efforts may be necessary in numerous locations. These efforts will be extremely costly and complex. The likelihood of successful population control or eradication programs is currently considered questionable at best and would be likely to cause negative impacts to the very resources we hope to protect.

Introduction

Eriocheir sinensis was first reported in south San Francisco Bay by shrimp trawlers in 1992. Though only established in California, it has been reported from the Detroit River (1965), Lake Erie (1973) (Nepsky and Leach 1973, as cited by Veldhuizen and Stanish 1999) and other areas of the Great Lakes region (1973-1994) (Leach, pers. comm. 1994, as cited by Veldhuizen and Stanish 1999), and the Mississippi River Delta (1987) (D. Felder, pers. comm.1995, as cited by Veldhuizen and Stanish 1999). A close relative, *E. Japonica*, was reported from the mouth of the Columbia River in April 1997 (Aitkin, pers. comm. 1997). It also was reported to be available for live purchase in seafood markets of New York City China Town in the fall of 1998 (D. Jung, pers. comm. 1998). In the San Francisco Estuary and associated watersheds the Chinese mitten crab population has expanded it's distribution each year (Figure 1). It seems likely that the potential distribution of the crab will involve most of the state of California (Figure 2). The population numbers have also increased dramatically in the few short years since the species established in California (Figure 3). For more detailed information on the crab, a Service-funded literature search and report on the current level of knowledge on this species is presented in Appendix A. It includes sections on life history, distribution and abundance, dispersal mechanisms, environmental tolerances, impacts and control.

The Chinese mitten crab is a catadramous species, i.e. reproduction occurs in water of higher salinities then the juveniles migrate upstream to freshwater areas to rear in the spring. In the fall, adults migrate back downstream to brackish water where they mature and reproduce (Figure 4). It is during the migration times that the crabs become readily apparent and create problems for water diversions. The large numbers of migrating adults caused severe problems for the fish salvage operations of the water diversion projects during the Fall of 1998. There are two such facilities (State and federal) which pump and divert several million acre feet of water from the Delta annually. The fish salvage section of the facilities screens diverted water, attempts to salvage the fish entrained and relocate them downstream of the facilities. At peak times of the 1998 fall migration period, estimated fish mortality attributed to the crabs at the federal facility was 98-99% (S. Siegfried, pers. comm. 1998). An estimated 1 million crabs were entrained at this federal facility alone, up to 40,000 per day (USBR unpublished data, as cited by Veldhuizen 1999). The federal facility saw more crabs during a peak period, then catches more rapidly declined. While the crabs were not enumerated at the State facility, a like number may have been entrained there too. The State facility didn't see the extreme numbers during the peak, but they saw large numbers for an extended period of time. The larger overall facility design resulted in easier accommodation of the crabs, but the added crab handling expenses incurred there during the Fall of 1998 are estimated to be $20,000 (R. Wakefield, pers. comm. 1999). The 1998 crab take at the facilities was an increase from approximately 25 crabs total from both facilities in 1996 and perhaps 20,000 total entrained at the federal facility in 1997 (USBR unpublished data, as cited by Veldhuizen and Stanish 1999). Also reported to California Department of Fish and Game during the fall of 1997 and 1998 was mitten crabs clogging cooling water intakes of Pacific Gas and Electric power plants in the Delta (Hieb, pers. comm 1998). There is significant concern that similar problems will be faced by the extensive fish passages and water diversions in the Pacific Northwest and as well as industry in the Hudson River and other locations.

These concerns are not without precedent in other very different ecosystems. For example, the establishment of the Chinese mitten crab caused negative impacts in Germany in the early 1900s which have been reported in the literature but not yet observed in California (Veldhuizen and Stanish 1999). The crab was reported to have proliferated and spread so successfully in Germany as to negatively impact levees through burrowing and fisheries through interfering with the catch and damaging nets (Panning 1939). Since the 1930's Germany has seen five periods of high crab densities (1930-39, 1953-1960, 1969-75, 1979-1983, 1993-present. In 1998, it appeared that the numbers of crabs reported in the Elbe River was comparable to the experience of the 1930's. Population decreases are believed to be related to pollution impacts to prey species, mortality of larval crabs due to cold spring temperatures and water flows (Gollasch 1999). The Thames River estuary has also witnessed an large increase in the population of crabs since 1992 from a relatively constant background number since the 1970s (Clark 1998).

There is evidence of mitten crab burrowing in California, with the highest concentration in south San Francisco Bay creeks (Halat 1996 as cited by Veldhuizen and Stanish 1999). Based on currently available data, damage to levees or banks will depend on crab densities, levee structure and bank suitability and will most likely occur in tidally influenced areas (Veldhuizen and Stanish 1999). The San Francisco Estuary and it's watersheds rely heavily on levees for flood protection and water diversion. Threats to this system like those posed by the mitten crab are very serious, given the dependence on the levee system.

These waterways also support a large recreational fishery and commercial fisheries for crayfish and grass shrimp (Table 1). The most widely reported impact from the crab in California to date is the interference with recreational fishing through bait stealing (Hieb pers. comm 1998). Commercial bay shrimp and crayfish fishermen have also reported the mitten crab present in their nets and traps, interfering with these enterprises (Hieb, pers. comm. 1998). Similar reports are present in the German literature.

In China and Korea the crab is reported to damage rice crops by feeding on young rice shoots (Ng 1988, as cited by Halat 1996). The Bay-Delta is located in the Central Valley of California which is known for productive harvests and the variety of agriculture crops grown here. Among them is a large rice industry located near Sacramento, well within the current extent of the mitten crab invasion.

The crab is also considered a human health concern as it is the secondary host for the Oriental lung fluke, *Paragonimus westermani*. Symptoms of infection are typically tuberculosis-like. Mammals, including humans, are the final host of the lung fluke, with infection likely through the ingestion of raw or undercooked infected crabs or transfer of the fluke by contaminated utensils (USFWS 1989, Marquardt and Demaree 1985, as cited by Veldhuizen and Stanish 1999). It should be noted that the lung fluke has not been reported in the California mitten crab population. There also is concern that the crab may bioaccumulate contaminants as they have been known to inhabit agricultural ditches and other areas which may contain elevated contaminant levels (Veldhuizen and Stanish 1999).

The ecological impacts of large populations of mitten crabs have not been investigated to date. Mitten crabs are omnivorous, becoming more carnivorous as they mature. It is suspected that a large population of mitten crabs could change the structure of the estuary's foodweb and affect the abundance and growth rates of various species through competition and predation effects (Veldhuizen and Stanish 1999). As the San Francisco Bay-Delta estuary is home to a variety of endangered or threatened species, these potential impacts are of great concern. For a summary of mitten crab impacts, see the conceptual model in Figure 5.

It should be noted that California Department of Fish and Game regulations bar the possession and transport of live crabs from the genus *Eriocheir* (Section 671, Title 14). However, it is currently considered legal to catch the crab in the inland waters of California with a hook and line if you possess a valid fishing license. We have received reports that people are catching the crab for human consumption and for use as bait. The genus Eriocheir is also listed as an injurious species under the federal Lacy Act which bars the importation of live crabs (USFWS 1989).

As we have learned more about the potential negative impacts, the population increases and proposals for action, we have come to recognize the need for management action. A cooperative effort has evolved for development of a draft National Management Plan. This draft Plan highlights the issues, conclusions and recommendations of a public meeting, the literature search report, the Interagency Ecological Program (IEP) Mitten Crab Project Work Team (PWT) and a public workshop sponsored by the U.S. Fish and Wildlife Service, San Francisco Estuary Project, University of California, Davis Cooperative Extension and the Western Regional Panel on Aquatic Nuisance Species on March 23, 1999 in Sacramento, California. The goals of the workshop were to:

- Provide information about the crab, management issues and concerns
- Develop cooperative working relationships
- Identify specific needs
- Make recommendations for action and tasks

This workshop was attended by approximately 125 individuals representing diverse interests including agencies, academia, legislators, environmental groups, exporters, commercial fisherman, regulators, animal rights groups and other interested parties. The first part of the day was reserved for providing information on the many areas of interest in formulating a management plan. The second part of the day was spent in break-out groups in an effort to develop detailed information for inclusion in the management plan. The break-out groups were:

- Preventing spread
- Reducing impacts
- Detection and monitoring
- Controlling populations.

The discussions were facilitated and recorded and form the basis for the draft Plan when combined with input contributed from other meetings, individuals and entities. An outline of the Workshop Recommendations is presented in Appendix B.

Table 1. Estimated values of selected San Francisco Bay-Delta Fisheries.

Type of Fishery	Targeted Stock	Approximate Annual Value	Value Type	Year of Data
Recreational	Anadramous fish	$98 million	Impact, of activities	1985*
Commercial	Crayfish	$750,000	Retail, of catch	1998**
Commercial	Grass shrimp	$1.5 million	Retail, of catch	1998**

* The Economic Value of Striped Bass, Chinook Salmon and Steelhead Trout of the Sacramento and San Joaquin River Systems. Report to the State of California. California Department of Fish and Game. 1985

** CALFED Ecosystem Restoration Program Plan. CALFED Bay-Delta Program. 1998.

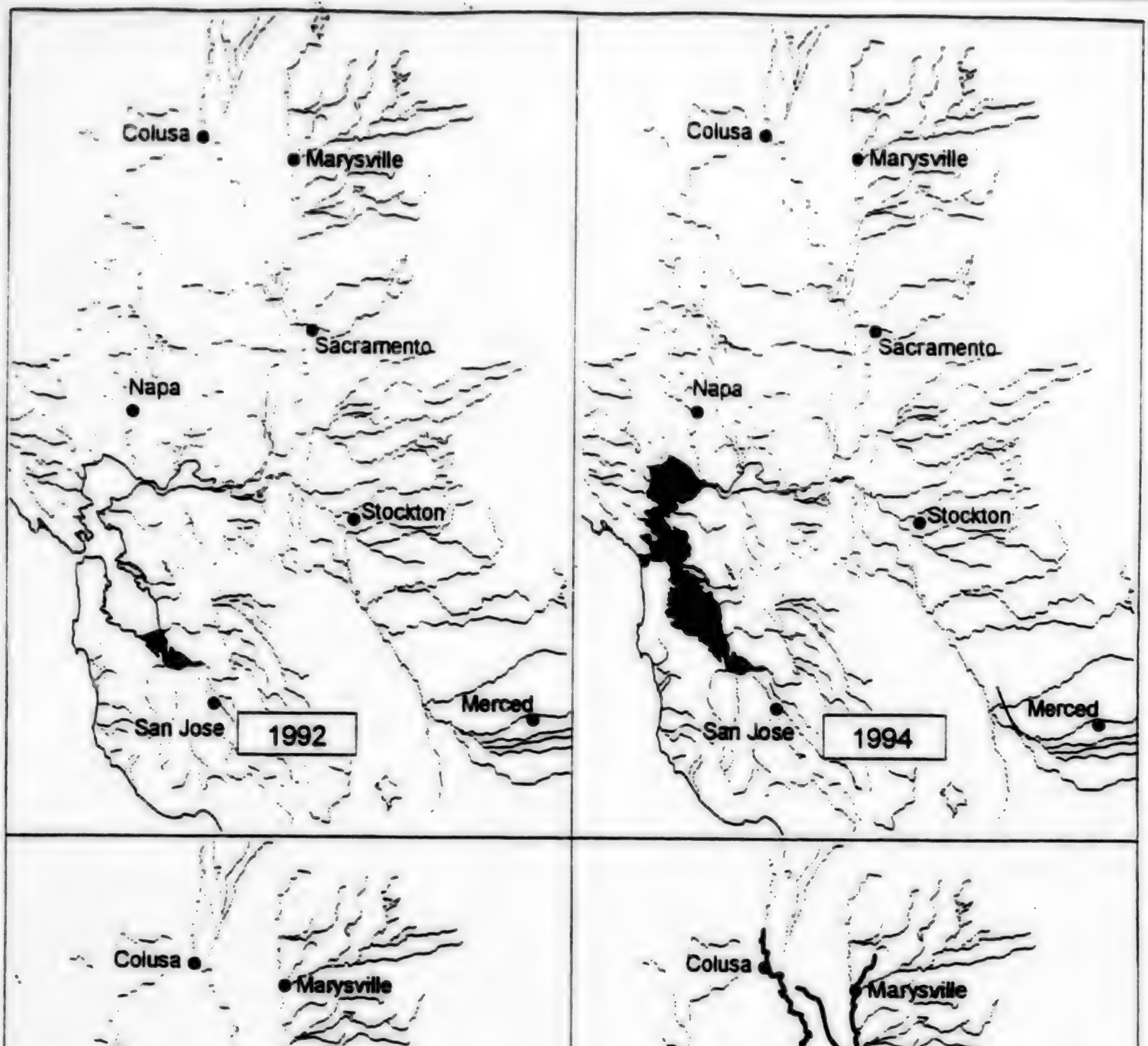


Figure 1. **Expansion of the Chinese mitten crab distribution in the San Francisco Bay-Delta.**

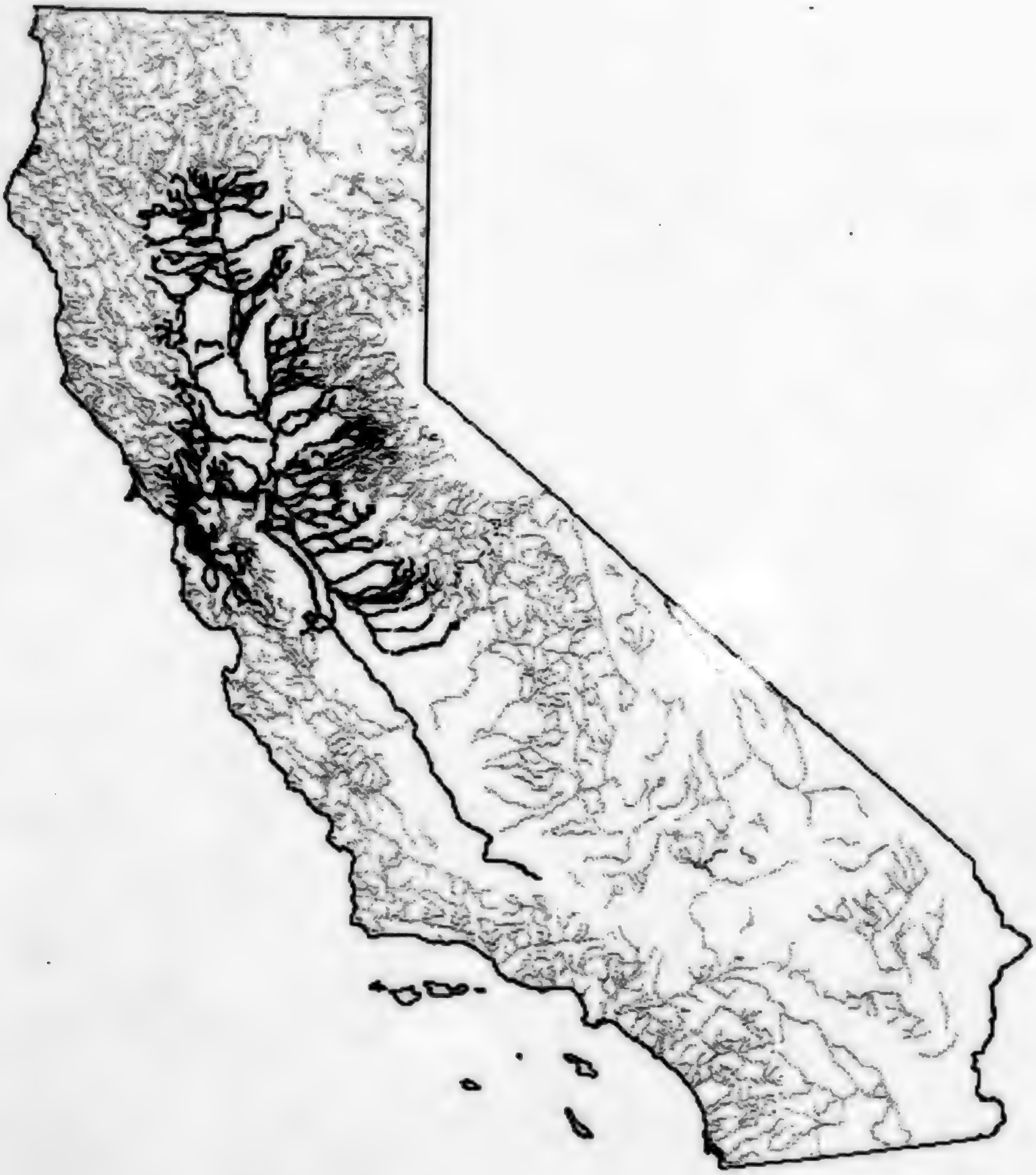


Figure 2. Potential distribution of the Chinese mitten crab in California.

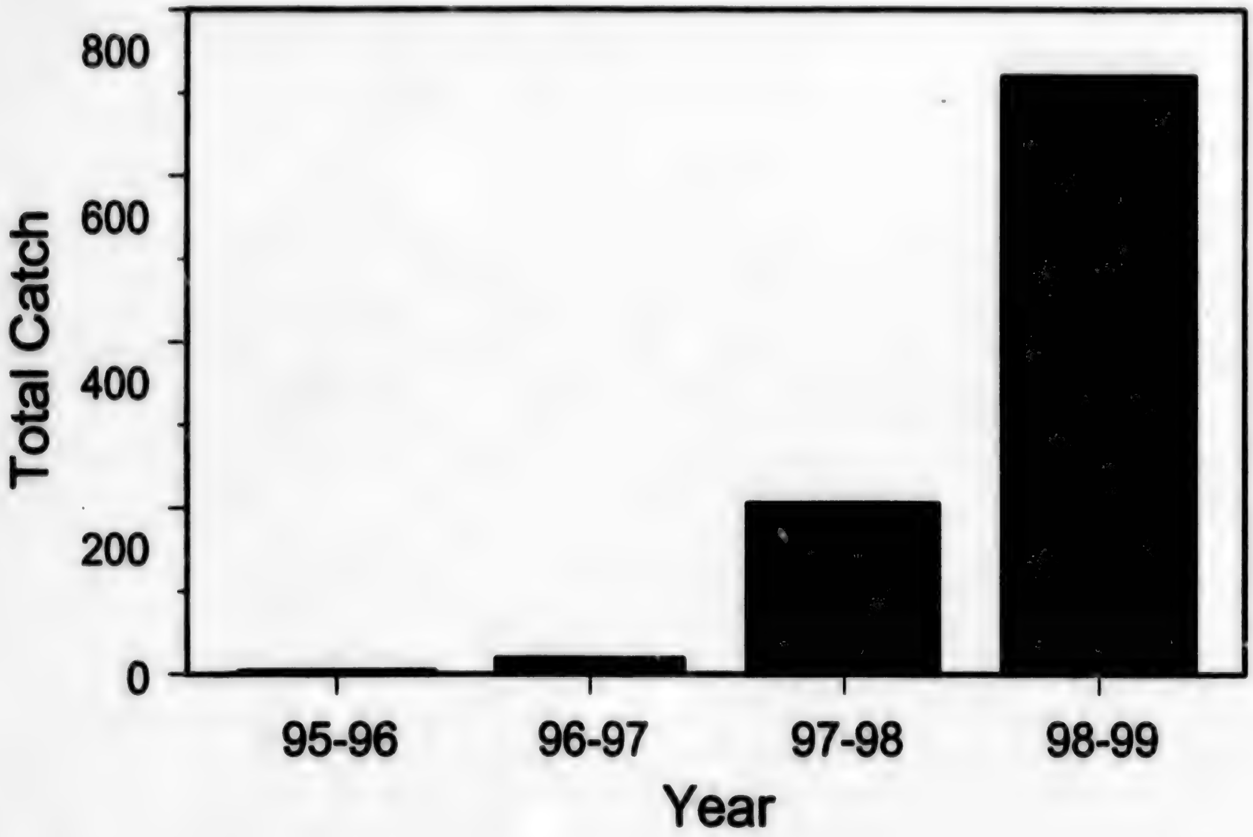


Figure 3. Adult Chinese mitten crab catch from the San Francisco Bay Study otter trawl survey, September-May, 1995-1999.

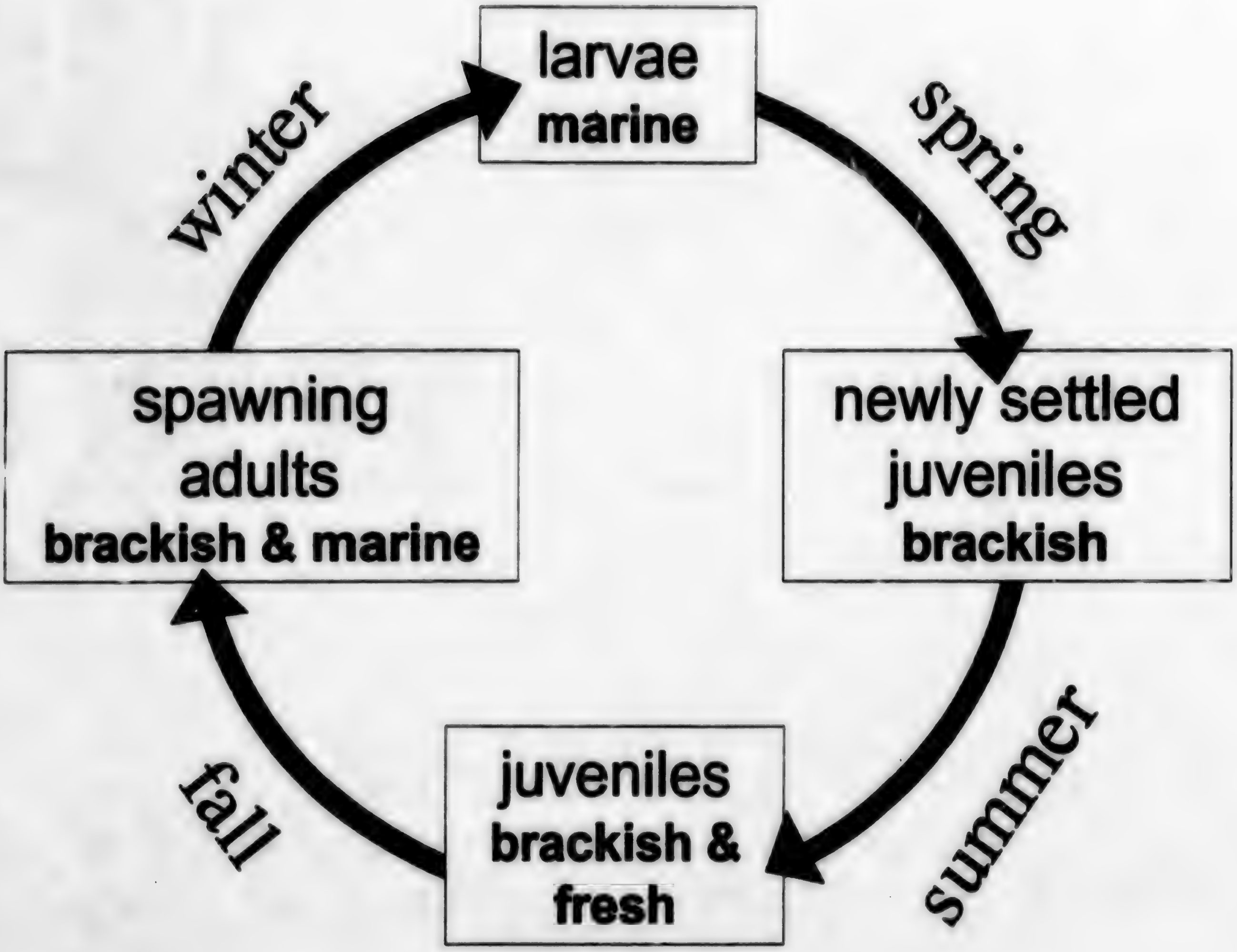


Figure 4. Chinese mitten crab life cycle.

Developing the Management Plan

This draft Plan has been developed with contributions and input from a broad range of interested parties through various means of participation. To summarize the activities that have provided opportunities for input:

-An interagency public meeting was held at the Tracy Fish Salvage Facility, Bureau of Reclamation, in September of 1998. Prior to this meeting, many tours of the crabs and facility operational problems had been given to interested individuals and groups. The media had actively reported on the invasion and impacts.

-By the end of 1998, the IEP had formed a Mitten Crab PWT with several subteams such as: Ecology, Levees, Public Health, Agriculture, and Fish Facilities. All participants in the public meeting were invited to participate and attendance remains open to all interested parties. The IEP supports a broad interagency program of biological research and monitoring of the San Francisco Bay-Delta estuary.

-The California Department of Fish and Game (CDFG) developed a website, message center and fact sheet of frequently asked questions. (www2.delta.dfg.ca.gov/mittencrab/html)

-The U.S. Bureau of Reclamation has also developed a website on mitten crab at www.mp.usbr.gov/mittencrabs.html

-The U.S. Bureau of Reclamation and California Department of Water Resources developed draft management plans for fish salvage operations in cooperation with endangered species regulators (California Department of Fish and Game, U.S. Fish and Wildlife Service, and National Marine Fisheries Service).

-The U.S. Fish and Wildlife Service coordinated the September 1998 public meeting and the March 1999 Mitten Crab Workshop. The Service also supported a literature search and report which was distributed at the Mitten Crab Workshop and will soon be accessible on the ANS Task Force website (www.anstaskforce.gov).

All individuals and organizations with interest in the subject have been encouraged to contribute. Mitten Crab Workshop participants include representatives from:

Action For Animals
AEB
California Department of Water Resources
California Department of Fish and Game
California Department of Public Health
California Department of Food and Agriculture
California Environmental Protection Agency
California Fish and Game Commission
California, Oregon and Washington Sea Grants
California Rice Promotion Board
California Rice Research Board
California State Water Resources Control Board

California State University, Hayward, Fresno and Sacramento
Cargill Salt
County Agriculture Departments of Glenn, Sutter and Colusa counties
Delta Protection Commission
H & N Fish Company
IEC America
Institute for Marine Sciences, Germany
Kjeldsen, Sinnock, & Neudeck
Law Offices of Jung & Jung
Levine-Fricke
London Museum of Natural History
Marine Science Institute of Redwood City
National Marine Fisheries Service
Pacific Coast Federation of Fisherman
Pacific Fisheries Legislative Task Force
Portland State University
Queen Mary & Westfiled College
Reclamation Districts 800, 2035 and other levee maintenance organizations
Sacramento and Stone Lakes National Wildlife Refuges
Sacramento County Flood Control
San Francisco Estuary Institute
San Francisco Estuary Project
San Francisco Regional Water Quality Control Board
Santa Clara Valley Water District
Smithsonian Environmental Research Center
State Parole Board
Strategic Environmental
Tulalip Tribes Fisheries Department
University of California, Davis, Berkeley and Santa Barbara
University of Washington
University of London
U. S. Bureau of Reclamation
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
U.S. Geological Survey
Washington Department of Fish and Wildlife
West Basin Research Association
And many other public officials and private citizens

The goal of the Plan has evolved through the discussions of the above forums to cover the two overriding areas of interest and concern at this point which are; Controlling spread of the crab to new areas and Reducing negative impacts from existing populations.

Management Plan Goal: **Prevent or delay the spread of *Eriocheir* species to new areas and reduce the negative impacts of existing populations.**

This goal, while stated simply enough, may actually require action in complex biological systems where many complications and considerations will arise. For example, the San Francisco Estuary, the Sacramento and San Joaquin rivers and their watersheds are systems that support numerous species of special concern. An extensive restoration effort led by the interagency group known as CALFED is now underway there. This system, through water diversions, also provides irrigation water for over 4.5 million acres of farm land and a significant portion of the drinking water for over 20 million California residents. Mitten crabs may also establish populations in other watersheds at risk. These systems may be comprised of various elements and structures which are also not easily adaptable to eradication and control efforts. Pursuit of the Management Plan Goal will, of necessity, be sensitive to the many restrictions placed on specific actions due to such special circumstances (endangered species, water needs, water quality concerns, impacts to environment, etc.) that exist in the waters of concern.

Management Objectives:

The work groups determined that there are various elements of research, outreach and management which pertain to each of these objectives:
a) Prevent Spread
b) Promptly detect new populations and monitor status of existing populations
c) Reduce the negative impacts of crab populations
d) Develop strategies and methods for population control

Please see Appendix B for an outline of the Workshop Recommendations.

Problem Definition

To help define the problem, we have used elements of an ecological risk assessment as described in the Ecological Risk Assessment Guidelines (U.S. Environmental Protection Agency 1998) and the Generic Nonindigenous Aquatic Organisms Risk Analysis Review (Aquatic Nuisance Species Task Force 1996). This includes the development of a conceptual model which reflects how the mitten crab may impact various economic and environmental resources and ways in which we may measure those impacts (Figure 5).

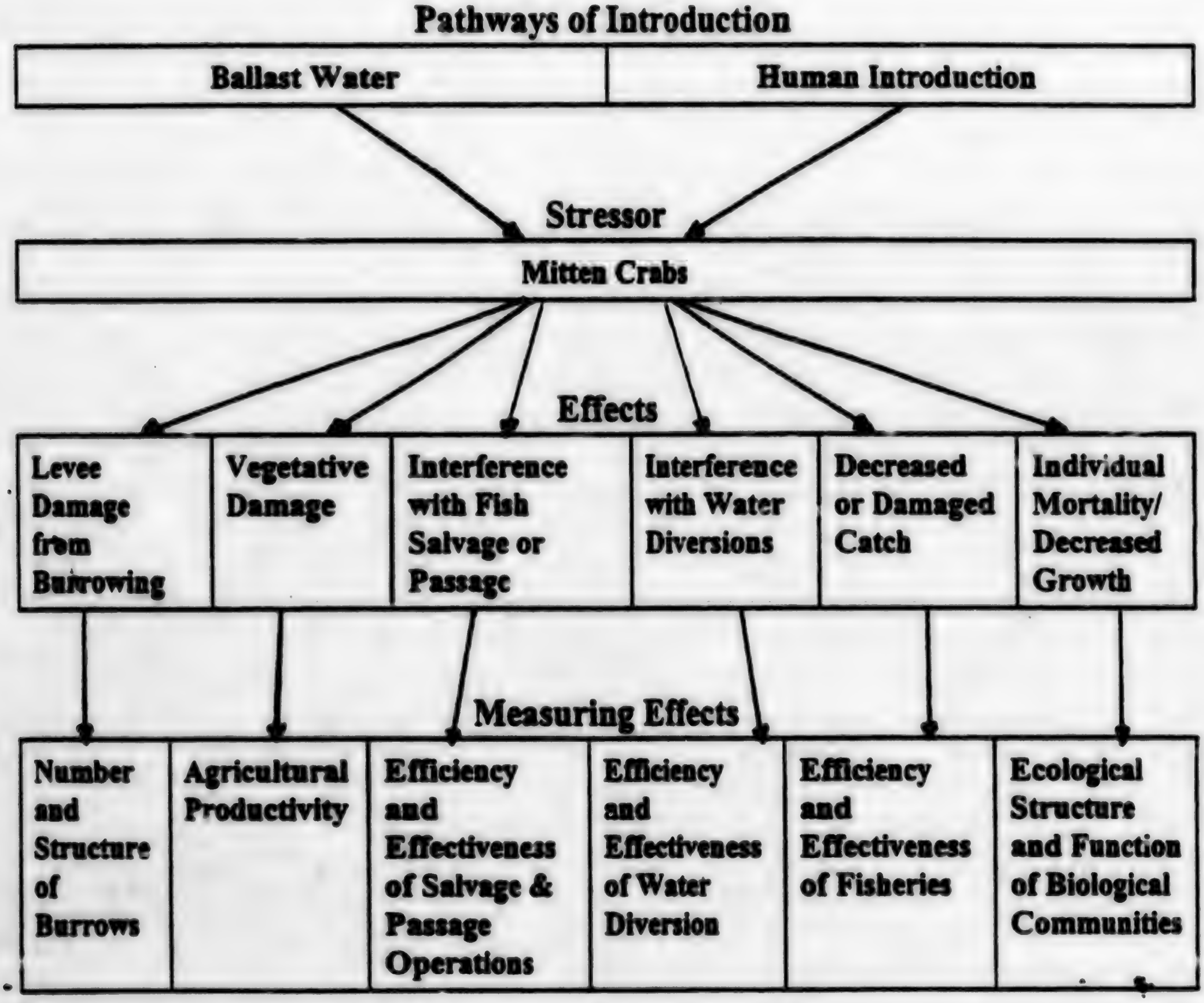

Pathways of Introduction
Ballast Water
Human Introduction
Stressor
Mitten Crabs
Effects
Levee Damage from Burrowing
Vegetative Damage
Interference with Fish Salvage or Passage
Interference with Water Diversions
Decreased or Damaged Catch
Individual Mortality/ Decreased Growth
Measuring Effects
Number and Structure of Burrows
Agricultural Productivity
Efficiency and Effectiveness of Salvage & Passage Operations
Efficiency and Effectiveness of Water Diversion
Efficiency and Effectiveness of Fisheries
Ecological Structure and Function of Biological Communities

Figure 5. *Eriocheir* Risk Assessment Conceptual Model

Conceptual Model Summary

Pathways of Introduction

The possible pathways of introduction for the Chinese mitten crab may include many of those pathways which are typical of nonnative invasive species introduction. Two pathways have been identified as the most likely modes of introduction to the San Francisco Bay-Delta. These are ballast water releases and intentional human introductions. The probability of establishment of the mitten crab to new environments is quite high if the environmental conditions are favorable, ballast water releases from infested waters occur and/or intentional human introductions occur.

Ballast water releases appear to be a possible pathway for the introduction of all life stages of mitten crab. Taking on ballast water is a process which is currently an essential part of normal shipboard operations. It begins with a ship taking up water in order to stabilize the vessel. Depending on variations in ship sizes, routes, and loads, the amount taken up may be millions of gallons. In the process of pumping this water into the large holds of the ship, many living organisms can also be taken in. These organisms are often capable of surviving the voyages and the release of the water into a new location. A ballast water survey currently underway has documented the transport of Decapod (crab) larvae from the San Francisco Bay estuary to Port Valdez, Alaska in oil tankers ballast water (Ruiz, pers. comm. 1999). Ballast water release is believed to be the introduction mechanism of the mitten crab to Germany, England, Lake Erie, and the Mississippi River (Ingle 1986, Peters and Panning 1933, Panning 1939, Nepszy and Leach 1973 as cited by Veldhuizen and Stanish 1999), though it is not clear what particular life stages may have been transported. It has also been noted that hull fouling may contribute to mitten crab introductions (Gollasch 1999).

Human introduction also appears to be a significant pathway for the establishment of mitten crabs, both accidentally and intentionally. The mitten crab is a highly valued food item in China. Mitten crabs have been found in carry-on luggage at Seattle, Los Angeles, and San Francisco airports and have been illegally imported live to markets in Los Angeles, New York and San Francisco (Cohen and Carlton 1997, D. Jung, pers. comm. 1999). There is significant interest in both commercial fisheries and aquaculture production industries to meet the demand for the crab as a valued food item. For these reasons, it is widely speculated that intentional releases of crabs into San Francisco Bay waters has occurred in an effort to establish a harvestable population Levees and banks may be undermined or weakened due to burrowing.

Potential Effects of the Chinese Mitten Crab

-The impacts of predation, competition, habitat alteration and/or foodweb disturbance on biotic populations could lead to a decrease in biotic populations or a change in the community structure.
-Fish in fish salvage or fish passage operations may face increased mortality due to the presence of mitten crab in the facilities.
-Levees and/or banks could be weakened due to mitten crab burrowing, leading to increased maintenance requirements, slumping and/or failure of banks and/or levees.
-Increased populations of mitten crab could contribute to a decrease in vegetation in agriculture fields and/or natural habitats.
-Water Diversion Activities are subject to interference due to crabs blocking or clogging systems.
-Recreational and Commercial Fishing are subject to interference and reductions in opportunities/efficiencies due to blocking/clogging of traps/nets, bait stealing and/or damage to gear or catch.

Measuring Effects

The effects of the mitten crab populations can be measured by establishing the areas of concern and documenting the divergence from historical records. A determination of the impacts can be developed using measurements of the following indicators;

-Population Levels of Crayfish, Benthic Invertebrates, and other species
-Fish Survival at Fish Salvage and Passage Operations
-Extent of Burrowing (Concentration, Depth, Design, and Structure)
-Agriculture Crop and Aquatic Vegetation Productivity
-Decrease in Diversion Efficiencies
-Decrease in Fishing Efficiencies, Condition of Catch, Quality of Experience and/or Increase in Gear Maintenance

Implementation

The development of the Plan has highlighted two strategies important to successful implementation:

A) Cooperative intergovernmental initiative with participation from academia, commercial industries, stakeholders, agencies and other interested parties.

B) Implementation will occur in stages to allow safe, controlled and experimental immediate start. Only those actions which are deemed not to cause more harm than they prevent and are carefully designed to be compatible with an adaptive management approach will be considered. Such actions will incorporate adequate controls go forward as experimental. Successful experiments will advance further investigation through a rational, systematic expansion, using adaptive management principles to assess feasibility and effectiveness and to modify goals/objectives or strategies/actions as needed.

The following is an outline of the Actions and Tasks which have been identified as appropriate and necessary for management of the mitten crab and are recommended for implementation. Actions/Tasks of one subject area may build upon or be requisite for actions/tasks from another subject area. The integration of the actions/tasks will be further developed in the summary which follows the outline.

Implementation Outline

Phase I

A. Monitoring:
  1) Develop and refine standard sampling methods and protocols.
  2) Establish cooperative monitoring survey for the San Francisco Bay-Delta Estuary and associated watersheds to monitor status and detect spread
  3) Develop/refine early detection strategies
  4) Establish early detection networks on West Coast (e.g., fish passage and hydropower facilities)
  5) Develop cooperative agriculture and levee monitoring programs

B. Information and Education:
  1) Develop/distribute identification and outreach materials to support detection efforts along West Coast
  2) Develop Rapid Response Plan for crabs detected in new areas.
  3) Develop prevention materials to distribute entities involved in activities identified as creating risk to uninfested areas on West Coast
  4) Develop/distribute Best Management Practices for West coast industries that may use the crab

5) If crab is determined to represent a public health risk, develop/distribute materials in California and other population centers likely to be at risk detailing public health risks and preventive measures

6) Develop/distribute education/outreach materials for agriculture and levee districts in California and to facilitate monitoring and reporting observations and impacts.

C. Research and Development:

1) Life history/population biology studies looking for vulnerabilities to be exploited

- A) Crab behavior
- B) Environmental tolerances
- C) Impacts to Habitats (use by juveniles and adults)
- D) Impacts to native biotic community
    - Prey and dietary shifts with age
    - Competition with other species
    - Predation on eggs and larvae, esp. salmonids, sturgeon, delta smelt and others
    - Disease transfer
    - Habitat alteration
- E) Migratory behavior
    - Cues and timing
    - Substrate preferences
- F) Recruitment dynamics
- G) Physical controls
    - Traps/Sinks
    - Barriers - electric and others
- H) Biological controls
    - Predators
    - Viruses
    - Parasites

2) Public Health Concerns

- A) Contaminants
    - Bioaccumulation?
- B) Lung fluke
- C) Disease transfer

3) Impacts to Levees

4) Impacts to Agriculture

- Crops
- Irrigation

5) Evaluate case studies of introduced species control programs for effectiveness

D. Evaluate mitigation measures for water diversions

1) Screens

        - 2) Barriers
        - 3) Traps/Sinks
- E. Plan Evaluation and Revision (Adaptive Management)
    - 1) Public workshop to review results of FY 00 work
    - 2) Develop recommendations for Plan adaptations
    - 3) Distribute for review and comment
    - 4) Submit revised recommendations and Plan to ANS Task Force

Phase II

- A. Monitoring
    - 1) Develop standard detection program for Mississippi River and Hudson River based on West Coast program
    - 2) Expand the West Coast program to areas identified as priorities in annual evaluation (IE)
- B. Information and Education
    - 1) Develop outreach and education program for other areas at risk
- C. Research and Development
    - 1) Implement exclusionary measures by physical control methods (such as traps, sinks, electrical barriers) as experimental tests
- D. Evaluate and Implement Control Strategies
    - 1) Identify enforcement, compliance and monitoring costs for exclusion programs
    - 2) Initiate evaluation of control fisheries, based on results and recommendations of case study evaluations of other such efforts (IC5)
    - 3) Initiate evaluation of limited bounty harvest program for hook and line take
- E. Plan Evaluation and Revision (Adaptive Management)

Phase III

- A. Monitoring
    - 1) Continue monitoring programs
- B. Information and Education
    - 1) Continue existing education and outreach programs
- C. Research and Development
    - 1) Using adaptive management, determine efficiencies of exclusionary program and test other methods of take for comparison.
- D. Development and Implementation of Control Strategies
    - 1) Test and implement as appropriate, other methods of take.
- E. Evaluate Implementation and Results
    - 1) Use adaptive management to evaluate the actions implemented and the impacts on annual basis. Incorporate experiences into future work plan.

Implementation Summary

An Implementation Table (Table 2) which displays recommended projects and associated funding follows this section. This table is included in an attempt to provide further information to interested parties on the background, status and needs for mitten crab management.

Proposed Recommendations for Management Actions-

Please see Appendix C and Appendix D for descriptions of the actions currently planned and underway at the State and Federal Fish Salvage Facilities in Tracy, California. The Service is working with the facility operators to develop permits for the describe experiments which will include monitoring and evaluation plans.

Successful implementation of the Management Plan will entail the coordination and integration of the numerous interrelated components of the Actions/Tasks. It is essential that coordination continue to be provided through existing channels as a minimum. The following discussion details the overlap and prerequisites of the Actions and Tasks identified in the Implementation Outline, with accompanying reference labels in parenthesis.

The Plan identifies a Phase I. Monitoring and Detection component that calls for the development of standard detection and sampling methods and protocols (IA1 & IA3). There is a Habitat Use study under way that is currently attempting to develop such methods for some life stages. This study is funded by the IEP and implemented by DWR. As part of the IEP, the results of this study will be shared with the members of the IEP Project Work Team, enabling other projects to build upon this initial work. As the methods are developed, the establishment of monitoring program for San Francisco Bay-Delta estuary and watersheds and detection programs for the Pacific Northwest, including the Columbia River basin will be developed (IA2 & IA4). At the same time, cooperative agriculture and levee monitoring programs will be developed in an attempt to monitor and document potential impacts to these concerns (IA5). All of these efforts will rely on the development of information detailed in the Information and Education component (IB1, IB5-IB6).

The detection component of this Plan will begin with the development of a monitoring network on the lower Columbia River (IA4 & IB1). This network could be coordinated by Dr. Mark Sytsma of Portland State University who serves as the Aquatic Nuisance Species Coordinator for the Pacific States Marine Fisheries Commission. It will consist of education and outreach to the organizations presently working and/or recreating in the area to enable them to identify and report the detection of mitten crabs. An outreach video planned by the Pacific Northwest Marine Invasive Species Team will be especially useful for this effort. Further complimenting this effort will be the development of a Rapid Response Plan (IB2) which will identify the protocols and procedures to be followed in the case of crab detection. This detection network and Rapid Response Plan will provide models for such efforts in other areas. It is anticipated that the State of Washington and the Pacific Northwest Marine Invasive Species Team will also work to develop complimentary outreach programs to address mitten crab in the Northwest. Phase II Monitoring identifies expansion of this detection program to areas of the Mississippi and Hudson Rivers and other areas of the West Coast which are identified as at risk due to past introductions of the crab, it's presence in live seafood markets, ballast water releases and/or ocean currents. See Appendix G for information on the Hudson River and anticipated impacts.

At the same time, there is special urgency to address the risk of spreading the crabs throughout the Pacific Northwest via ballast water and human introduction. A monitoring program to determine areas and timing of high numbers of crabs (especially larvae) in the San Francisco Bay area will enable the identification of "No Ballast Zones" during certain times of year. These zones will be areas for which the recommendation will be in effect that ballast water should not be taken on board because of the high risk of spreading mitten crabs (IB3). There is also a study proposed by California Sea Grant to assess the demand and use of the crab as a food item. This study is recommended as a first step to address the pathway of intentional human introductions. Budget information is underdevelopment. This study will identify the appropriate approaches to education, outreach and intervention. Both of these activities address (IB2 and IB3).

Proposed Recommendations for Research Activities-

The Research and Development component identifies the areas of crab life history and biology that need further investigation prior to furthering certain activities which may help reduce negative impacts or control populations. The Habitat Use study is underway (IC1C). The Benthic Impacts study has support from DWR and CALFED to initiate that work in early FY00 (IC1B). A three year study by UC Berkeley to Assess Ecological and Economic Impacts of Mitten Crab has support from CALFED beginning in FY00 (IA1&2, IC1). U.S. Bureau of Reclamation has provided support to the California Department of Fish and Game to investigate crab behavior and movement using telemetry. These studies will provide us with details about the crab which are mostly unknown at this point. Information on crab behavior, migratory cues, recruitment dynamics and environmental tolerances could lead to the development of methods to reduce negative impacts or even control populations, depending on findings (IC1A,B,E & F). Many studies to address other questions about life history and biology are awaiting support.

Some investigation of Physical Controls (K-rail, traveling screens and grizzly bars) will occur as part of ongoing projects undertaken by USBR and DWR at the fish salvage facilities (see Appendix C & D). Results of these studies will provide valuable information for the development of projects to further investigate these methods in FY 2000 and FY 2001. USBR has also provided funding ($40,000) to San Francisco Estuary Institute to perform mitten crab risk analysis of USBR water diversion facilities in the West.

A proposed method of reducing population numbers is through instituting bounty or harvest programs. It is recognized that such programs will promote the establishment of the mitten crab into other areas of the country because of the financial incentive. An appropriate approach to this dilemma is to support a study which will provide us with information about the success or failure of such programs which have been undertaken in the past as population control measures for introduced species.

Biological controls have been proposed for further investigation, but many people have serious concerns that such controls may not achieve or maintain species specificity and will impact other crustacean populations in the Bay-Delta. It is recommended that proposed biological control projects face rigorous study of the possible impacts to nontarget organisms prior to release.

A study of contaminants accumulating in the crabs will be conducted by the California Department of Health Services to investigate the public health risk of ingesting the crab (IC2). This will lead to development of outreach efforts if public health risk is identified (IB4). The Oriental lung fluke (*Paragonimus westermani*) has been identified as a public health concern. Centers for Disease Control (CDC) has advised Department of Health Services that a snail is the primary intermediate host for this parasite, the mitten crab is the secondary host and mammals are the final host. Neither the fluke nor the snail species that serve as the primary intermediate host in Asia have been reported in crabs here. There are however several freshwater snail species that could possibly serve as an intermediate host. CDC further advises that an investigation of the snails present and their ability to serve as such a host to the fluke would be the proper approach to resolving this question (IC2B) of whether or not this is a public health concern in California. A study to evaluate this question has been proposed by University of California, Santa Barbara scientists for National Sea Grant funding.

At the conclusion of FY 00, an interagency workshop will be held in conjunction with the IEP mitten crab PWT and CALFED NIS Program to summarize the results and findings of the tasks and studies completed and ongoing (IE1). The information generated will be the basis of the adaptive management and program evaluation process. The information will be used to further refine this plan and develop the appropriate projects for FY01.

Table 2. Implementation Table

				Recent efforts ($000/FTEs)		**Planned Efforts ($000/FTEs)**		
TASKS/ACTIONS		**Fund source**	**Imp. Entity**	**FY 98**	**FY 99**	**FY 00**	**FY 01**	**FY 02**
#/Activity	**Description**							
	Literature search & Report	FWS			*2			
	Workshop	FWS/UCD /SFEP /WRP	SFEP		*17			
	Monitoring Programs (Burrowing/crayfish/ life stages)	IEP UCB	CDFG UCB	* *33.5	*33.5	25	30	
IA2/Monitor IA3	Detect Upstream Spread					50	50	
IA1&2 /Monitor	Habitat Use Study-Standard monitoring	IEP CALFED	DWR UCB		*67	*40 *149		
IA5/Monitor IB6/Outreach	Interagency coordination			*	*	15/.3		
IA4/Monitor IB1&2 /Outreach	Lower Columbia Detection and Rapid Response Program		PSU			25/.5	25	
IIA1/Monitor IIB1/Outreach	Miss. & Hudson R.						50	
IB1/Outreach	Identification Materials	CDFG	CDFG	*		5	5	
IB3/Outreach	Prevention Materials				*	20	30	
IB4/Outreach	Assess Demand & Use for Food		CaSG			**		
IC2/Research	Contaminants Study	DHS	DHS		*			

	Salvage Facility R&D	USBR	USBR		*	**		
	Salvage Facility R&D	DWR	DWR		*	**		
	USBR Facility Risk Assessment	USBR	SFEI		*40			
IC1/Research	Benthic Impacts	CALFED	DWR			*147		
IC1/Research	Evaluate physical controls		USBR /DWR			*50?	**	
IC1/Research	Migratory Cues	USBR	CDFG			*80		
IC5/Research	Evaluate control program case studies					25		
ID1/Facilities	Evaluation of activities	USBR/ DWR	USBR /DWR			**		
IE1/Eval	Evaluation Workshop		FWS			10	10	10

* Accomplished/Funded
** Budgets under development

Key to Table Abbreviations:

CALFED - Organization of State and Federal agencies working together to rehabilitate the San Francisco Bay-Delta Estuary and it's watersheds and provide for beneficial use of the resources.
CaSG - California Sea Grant
CDFG - California Department of Fish and Game
DHS - California Department of Health Services
DWR - California Department of Water Resources
FWS - U.S. Fish and Wildlife Service
IEP - Interagency Ecological Program
OrSG - Oregon Sea Grant
PSU - Portland State University
SFEP - San Francisco Estuary Project
SFEI - San Francisco Estuary Institute
UCD - University of California, Davis Cooperative Extension
UCB - University of California, Berkeley
USBR - U.S. Bureau of Reclamation
UCSB - University of California, Santa Barbara
WaSG - Washington Sea Grant
WDFW- Washington Department of Fish and Wildlife
WRP - Western Regional Panel on Aquatic Nuisance Species

REFERENCES

ANSTF (Aquatic Nuisance Species Task Force). 1996. Generic Nonindigenous Aquatic Organisms Risk Analysis Review Process. Report to the Aquatic Nuisance Species Task Force, Risk Assessment Committee. Arlington, Virginia.

Clark, P. et al. 1998. The Alien Chinese Mitten Crab, *Eriocheir sinensis*, in the Thames Catchment. Journal of Marine Biological Association of the United Kingdom, 78(4):1215-1221.

Cohen, A.N. and J.T. Carlton. 1997. Transoceanic transport mechanisms: introduction of the Chinese mitten crab, *Eriocheir sinensis*, to California. Pacific Science 51:1-11.

Gollasch, S. 1999. Current Status on the increasing abundance of the Chinese mitten crab *Eriocheir sinensis* in the German Elbe River. Abstract submitted to the U.S. Fish and Wildlife Service for the Chinese mitten crab Workshop, 6 pp.

Halat, K.M. 1996. The distribution and abundance of the Chinese mitten crab (*Eriocheir sinensis*) in southern San Francisco Bay, 1995-1996. M.S. Thesis, University of California, Berkeley, 80 pp.

Panning, A. 1939. The Chinese mitten crab. Annual Report Smithsonian Institution, 1938, pp. 361-375.

US EPA (United States Environmental Protection Agency). 1998. Guidelines for Ecological Risk Assessment (EPA/630/R-95/002F). Risk Assessment Forum. Washington, D.C.

USFWS (United States Fish and Wildlife Service). 1989. Importation or shipment of injurious wildlife: mitten crabs. Federal Register 54(98):22286-22289.

Veldhuizen T. and S. Stanish. 1999. Overview of the Life History, Distribution, Abundance and Impacts of the Chinese mitten crab, *Eriocheir sinensis*., 26 pp.

Overview of the Life History, Distribution, Abundance, and Impacts of the Chinese mitten crab, *Eriocheir sinensis*.

Tanya C. Veldhuizen

Stacy Stanish

California Department of Water Resources
Environmental Studies Office, Interagency Program
Sacramento, CA 95816.

Funding provided by the United States Fish and Wildlife Service

Printed by the California Department of Water Resources,
Environmental Services Office

March 1999

STATUS

The Chinese mitten crab, *Eriocheir sinensis* (H. Milne-Edwards 1854), is a recently introduced species to the San Francisco Estuary and associated watershed. The most probable mechanisms of introduction to the estuary were deliberate release to establish a fishery and accidental release via ballast water (Cohen and Carlton 1997). This species is native to coastal rivers and estuaries of Korea and China along the Yellow Sea (Panning 1939). The Chinese mitten crab is presently well-established throughout the San Francisco Bay, the Sacramento-San Joaquin Delta, and the mainstems of the major rivers and tributaries that flow into the estuary. Both the distribution and population size of this species continue to rapidly increase.

The establishment of this species in North America is of concern, because the crab is considered a pest in northern Europe. The crab was accidentally introduced to Germany in the early 1900s, proliferated and spread to many northern European rivers and estuaries, where it impacted local fisheries and levee integrity. The California Department of Fish and Game (CDFG) added the genus *Eriocheir* to its List of Prohibited Species (Section 671, Title 14) in 1986 (USFWS 1989). United States Fish and Wildlife Service (USFWS) added the genus to its injurious wildlife list under the Lacey Act in 1989 (USFWS 1989).

LIFE HISTORY

The Chinese mitten crab belongs to the Order Decapoda and Family Grapsidae. This species is native to China where it is commonly called the river crab or Shanghai crab (Tan et al. 1984). The Chinese mitten crab, like other species in the genus *Eriocheir*, is characterized by the brown setae densely covering the front claws, producing the appearance of "hairy" claws. However, very small juveniles (< 25 mm carapace width (cw)) rarely have setae on their claws. (See Ingle (1980) for detailed identification characteristics). The Chinese mitten crab is a catadromous species; adults reproduce in brackish or salt water areas while offspring migrate upstream to fresh or brackish water areas to rear.

Lifecycle

Larvae

Eggs are carried by the female under the abdominal flap until hatching. For proper egg development and adherence, salinity near 25‰ is required (Vincent 1996). Females carrying eggs were collected from the San Francisco Estuary in areas with a salinity of about 10‰, but it is unknown if these eggs successfully developed (CDFG unpublished data). Hatching occurs during the spring and early summer months in brackish water areas of estuaries (Anger 1991) (Table 1).

The larvae are planktonic for approximately one to two months and pass through a series of development stages: a prezoea stage (a brief, non-feeding stage), five zoeal stages, and a megalopa stage (Anger 1991, Kim and Hwang 1995). Optimal water temperatures for all larval stages range from 15 to 18 °C (Anger 1991). The prezoea and zoea I stage occur in lower estuaries at salinities between 10‰ to 25‰ (Anger 1991). Larvae in the zoea I stage are very euryhaline, tolerating a wide range of salinities, especially compared to the later zoeal stages (Anger 1991). This characteristic allows them to survive the variable salinity conditions of lower estuaries (Anger 1991). Early zoeal stages mainly occur at the surface of the water column and are transported by surface currents toward the mouth of or out of the estuary. The subsequent zoeal stages tend to occur in nearshore marine waters or in lower estuaries and have a reduced tolerance for low salinities. Stages IV and V are stenohaline with maximum survival at salinities of 32‰ (Anger 1991). The megalopae occur lower in the water column and have an increased tolerance to low salinities. Carried by onshore-directed near-bottom counter currents toward the coast and inner estuaries, the megalopae eventually settle to the floor from late spring to mid-summer and develop into benthic juvenile crabs (Anger 1991). If gradually acclimated to brackish water, metamorphosis from megalopa to juvenile crab can occur in salinities as low as 5‰, although 15‰ to 25‰ is optimal (Anger 1991). Thus, metamorphosis from megalopa to first juvenile instar can occur in both seawater and freshwater (Anger 1991). This finding is supported by field collections and laboratory observations (Peters and Panning 1933; Panning 1939, and Hinrichs and Grell 1937, as cited in Anger 1991; Anger 1991).

Under unfavorable conditions of low salinity (≤15‰) and temperature (≤15 °C), an additional zoeal stage and megalopa stage have occasionally been observed (Anger 1991). These additional stages are likely adaptations to a highly variable environment (Sandifer and Smith 1979, as cited in Anger 1991). Refer to the Factors Affecting Potential Distribution section below for additional information on Chinese mitten crab salinity and temperature tolerances.

Table 1. Timing of life stages of the Chinese mitten crab in various regions.

	Hatching	Settlement	Upstream Migration	Downstream Migration	Spawning Season
China-Korea	?	?	February-May	fall	?-May

Europe	?-July	?	March-July, peak variable between years	August-November peak: September	October-January?
San Francisco Estuary	January?-May?	?	year-round, with peak in spring	August-January peak: September-October	November-January?

Juveniles

Juvenile mitten crabs rear in brackish and fresh water areas. In tidal areas, they may burrow in banks and levees between the high and low tide marks in which they retreat during low tide and during the day for protection from predators and desiccation, or they may remain in the subtidal zone (Panning 1939, Kaestner 1970, Ingle 1986, Veldhuizen and Hieb 1998a). Burrows are typically found in vertical river banks but have also been found in firm marsh bottoms in areas that are dewatered during low tide and upstream of tidal areas (Panning 1939, Halat 1996, Veldhuizen 1997, Veldhuizen and Hieb 1998a, K. Hieb, CDFG, unpublished data). Mitten crab burrows angle slightly downward and are elipitical in shape (Panning 1939). However, crabs do not always construct their own burrows. In the San Francisco Estuary (Suisun Marsh), mitten crabs were observed utilizing burrows made by the introduced Harris mud crab (*Rhithropanopeus harrisii*) (Veldhuizen and Hieb 1998a). Mitten crabs may also utilize dense moist vegetation, root wads, debris, and shallow ponded water as cover during lowtide (Veldhuizen and Hieb 1998a). They apparently do not burrow as extensively in non-tidal areas, probably because they are not subject to desiccation (Veldhuizen and Hieb 1998a).

Results of a monitoring survey conducted in the San Francisco Estuary (Suisun Marsh and Sacramento-San Joaquin Delta) indicated burrowing crabs were most abundant in tidally influenced areas of low salinity (Veldhuizen 1997, Holmes and Osmondson 1998). Most burrowing crabs were found below the root profile of vegetation lining steep, clay banks (Veldhuizen and Hieb 1998a). Crabs in these areas were typically less than 25 mm cw.

A portion of the juvenile population remains in the subtidal zone during lowtide. Juvenile crabs in freshwater frequent areas with hard bottoms and submerged vegetation (Pape 1939, as cited in Nepszy and Leach 1973). In tidal, freshwater areas of the Sacramento-San Joaquin Delta, juvenile crabs were collected more frequently in shallow areas with dense submerged vegetation (especially *Egeria*) than in shallow, unvegetated areas (L. Grimaldo, California Department of Water Resources (CDWR), unpublished data). They also inhabit channel bottoms (CDFG, unpublished data).

During late winter through spring, large numbers of juvenile crabs migrate upstream (see Table 1). In China, juveniles migrate upstream from February to early May, and the onset of migration follows an increase in temperature (Tan et al. 1984, X. Fu, pers. comm. 1999). In Europe, they began migrating in March and continued through July, with the peak migration period varying between years (Peters 1938). The crabs were mainly observed travelling in the main channels but also entered smaller channels with slow moving water. The crabs traveled upstream at a rate of 1 to 3 km per day, depending on size, and were most active at night (Panning 1939, Kaestner 1970, Tan et al. 1994, Vincent 1996). Increasing water temperatures, high population densities, and food competition were hypothesized as migratory cues in Germany (Panning 1939, Ingle 1986).

In California during February and March of 1998, CDFG received several reports of large numbers of migrating juvenile mitten crabs. The United States Bureau of Reclamation's (USBR) Tracy Fish Collection Facility, which entrains and salvages fish from water diversions in the Sacramento-San Joaquin Delta, collected large numbers of juvenile mitten crabs in late January through February. In other areas of the watershed, the crabs were most noticeable in small creeks or when concentrated at the base of weirs or other migratory barriers. Mitten crabs were reported climbing over weirs in the Sutter and Yolo bypasses, such as the Sacramento Weir, in February and March 1998. Thousands of mitten crabs migrated up Mormon Slough and Littlejohns Creek, east of Stockton, California, during these same months. In most cases, the juvenile crabs migrated upstream. However, those entrained at the USBR fish collection facility were travelling with the current.

The migrating juvenile crabs ranged in size from 25 to 40 mm cw (1 to 1.5

inches), and at least 75% of the crabs observed were males (CDFG, unpublished data). The crabs probably reared in the delta during the previous year. Based on their size, these crabs were estimated to be nearly 1 year old (having hatched the previous spring) and would probably reach maturity by the subsequent fall (K. Hieb, pers. comm.).

Adults

Crabs reach maturity at 1 to 5 years of age, depending upon environmental conditions (Panning 1939, Cohen and Carlton 1995) (Table 2). During late summer to early fall, the mitten crabs undergo a puberty molt and migrate downstream, at a rate of 8 to 12 km per day, to salt water to reproduce (Panning 1939, Kaestner 1970, Anger 1991) (see Table 1). The gonads develop during the migration (Panning 1939). Mating and fertilization occur during late fall through winter. Ovigerous females are present winter through spring in Europe and have been collected at depths of 10 to 15 m in the outer Elbe Estuary in the North Sea (Anger 1991). In Korea, ovigerous females were collected as late as May in the lower estuary and tidal mudflats (Kim and Hwang 1995). In the San Francisco Estuary, ovigerous females have been collected November through May and are found mainly in South Bay, San Pablo Bay, and Suisun Bay (Veldhuizen and Hieb 1998a, CDFG unpublished data).

Spawning occurs in lower estuaries where the average salinity is 20‰ (Anger 1991), although Ingle (1986) and Vincent (1996) report that salinity above 25‰ is required for proper egg development and adherence. Females produce 250,000 to 1 million eggs and carry the eggs until hatching (Panning 1939, Cohen and Carlton 1995). Both sexes die within several months after reproducing (Kaestner 1970). According to Wolff and Sandee (1971), post-spawning crabs are collected in the lower estuarine regions of Holland until June-July; shortly thereafter only dead crabs are found. Panning (1938) reported that a small portion of the spawning population migrates back upstream after mating, but it is unclear whether these crabs survived just for several more months or to the next spawning season.

Growth and Maturation

The growth rate of the crab is inversely related to its size. According to Panning (1938), small crabs increase in size 24% between molts while large crabs (≥ 70 mm) increase only 11%. In Germany, crabs molt 6 to 8 times the first year, 4 to 5 times the second year, 2 to 3 times the third year, and 1 time per year thereafter (Panning 1939) (Panning defined a year as running from July to July, as hatching is complete by July). The frequency of molting is dependent on temperature and nutrient availability. Molting probably occurs more frequently in China and California as the water temperature is warmer than in Germany. This is suggested by the variation in age of maturity. Crabs mature at 3 to 5 years in Europe (Panning 1939), but only 1 to 2 years in China (Cohen and Carlton 1995) and an estimated 2 to 3 years in California (Table 2).

Table 2. Lifespan and size of the Chinese mitten crab in various regions.

	Lifespan	Average Adult Size (cw)	Maximum Size (cw)
China-Korea	1-2 yrs	?	?
Europe	3-5 yrs	56 mm	+70 mm
San Francisco Estuary	2-3 yrs	40-60 mm	86 mm

Hoestlandt (1948) examined the gonadal development of male and female crabs. As female crabs mature, the abdomen increases in width, the setae under the abdomen increase in length, and the setae on the claws and legs increase in length. Mature females (having undergone a puberty molt) are characterized by an abdomen nearly equal in width to the thoracic plate and abdominal setae equal to the width of the abdomen (Hoestlandt 1948). The ovaries begin to develop as early as July. As they develop, their color changes from being transparent or pinkish when immature to pink to orange to purple or brownish when fully mature (Hoestlandt 1948).

As male crabs mature, the setae on the claws and legs increase in length. The claw size and setae length of mature males is greater than that of females. Male crabs undergo a puberty molt between July and August (Hoestlandt 1948). The gonads begin developing after this molt (Hoestlandt 1948). Rapid development occurs August and September and full maturity is reached by October or November (Hoestlandt 1948). The crabs ranged in size from 35 to 66 mm cw (Hoestlandt 1948). All crabs over 55 mm reached maturity (Hoestlandt 1948). However, some crabs ranging in size from 35 to 45 mm cw did not mature (Hoestlandt 1948). In addition, Hoestlandt examined one male (46mm cw) collected in October in the spawning area. It had immature secondary sexual characteristics (did not go through a puberty molt) but had fully developed gonads. This suggests that the puberty molt is not always directly related to the development stage of the gonads (Hoestlandt 1948).

Diet

Mitten crabs are omnivores, with juveniles eating mostly vegetation, but preying upon animals, especially small invertebrates, as they grow (Tan et al. 1984). According to Kaestner (1970), the crab feeds by running backward and stirring up mud. Mitten crabs also glean food off the bottom's surface and consume submerged vegetation (pers. obs.). Thiel (1938) concluded from his examination of 3,000 mitten crab stomachs that vegetation accounted for two-thirds of the diet and animal matter accounted for the rest. The vegetation types found included filamentous algae, *Potomogeton*, *Elodea*, and *Lemna*. Types of animal material found in the stomachs included *Tubifex*, molluscs, *Daphnia*, *Gammarus*, *Corophium*, *Crangon*, and chironomids (Thiel 1938, Hoestlandt 1948). Thiel (1938) found no trace of amphibians, and fish were found in only 2.4% of the stomachs. Using specimens collected from the species native range, Tan et al. (1984) also found the crabs consumed mainly vegetation and detritus, but also found they consumed shrimp, fish, and aquatic insects. Hoestlandt (1948) found the crab fed mainly from spring to autumn, but some adult stomachs collected in winter were found to be one-third full.

German fishermen in the 1930s claimed the crabs caught and consumed fish and greatly impacted population levels. Panning (1939) and the results of Thiel's diet analysis discount this claim. The crabs are too slow to harm or capture most adult fish, as evidence by crabs and fish occupying the same aquarium for many months (Panning 1939). Hoestlandt (1948) suggested the crab was a serious competitor for food, but not a direct predator. However, Kaestner (1970) reported that fish are attacked at weirs.

Predators

Relatively little is known about the predators of the mitten crab. Predatory fishes, waterfowl, and aquatic birds were noted as predators of the mitten crab in Germany (Panning 1939). White sturgeon, striped bass, black bass, catfish, bullfrogs, loons, and egrets have been reported to prey upon the crabs in the San Francisco Estuary (Veldhuizen and Hieb 1998a, CDFG unpublished data). Other predatory fishes, river otters, raccoons, and other wading birds most likely consume mitten crabs.

DISTRIBUTION AND ABUNDANCE

Asia

The Chinese mitten crab is native to coastal rivers and estuaries of Korea and China along the Yellow Sea (Panning 1939). It inhabits the Changjiang River valley and northern China (Li et al. 1993). The mitten crab has been reported to migrate 1400 km (800 miles) up the Yangtze River from the Yellow Sea (Panning 1939). Although the crab is found far inland, it prefers low-lying regions near the coast (Panning 1939). In Korea, the crab is common in rice fields near the coast, but only occupies riverine habitats when inland (Panning 1939).

In an effort to increase the commercial fishery in the Guangdong Province, "seed" crabs from the Changjiang estuary were released in the Zhujiang River drainage and Yantian River (Li et al. 1993). Crabs were planted in the Zhujiang estuary from 1973 to 1981 and from 1987 to at least 1993 (Li et al. 1993). Within a few years, the crab population was abundant enough to support a fishery (Li et al. 1993). Introductions to the Yantian River occurred in 1983 and 1984 (Li et al. 1993). Thus, the current distribution of *E. sinensis* extends south of its natural range.

Europe

The Chinese mitten crab was accidentally introduced to and became established in northern Europe, where the population exploded and rapidly expanded in distribution (Panning 1939). The crab was probably introduced to Germany in the early 1900s, coinciding with a period of increased maritime traffic between Europe and eastern Asia (Ingle 1986, Panning 1939). The first report of a Chinese mitten crab was from the Aller River near Rethem, Germany, Weser River system, in 1912 (Panning 1939). The crabs were caught as by-catch in flounder nets at the mouth of the Elbe beginning around 1915 (Panning 1939). The first reports of the mitten crab present in nontidal reaches of rivers were made from above Hamburg, Germany in 1926 (Panning 1939). By 1927, large masses of crabs were reported in the same area (Panning 1939). During the late 1920s-early 1930s, the mitten crab invaded the Ems, Weser, Elbe, Havel, Oder, and Rhine rivers and the Midland Canal, spreading to the neighboring countries of Denmark, southeastern Sweden, southern Finland, Poland (then East Prussia), Czechoslovakia, the Netherlands, Belgium, northern France, and England (Ingle 1986, Peters and Panning 1933, Peters 1938, Panning 1939, Wolff and Sandee 1971). Juvenile crabs were reported as far inland as Prague, Czechoslovakia, which is 700 km (580 miles) up the Elbe River from the North Sea (Peters and Panning 1933, Panning 1939).

The artificial connection between the North and Baltic seas facilitated the spread of the crab to the Baltic coast countries, either through ballast water or ocean current transport of larvae (Panning 1939, Jazdzewski and Konopacka 1993). The crab reached the French mediterranean through the interconnecting canal system (Hoestlandt 1959, as cited in Cohen and Carlton 1995).

By 1930, population control measures were required in Germany. The total catch of crabs in Germany was estimated at 262,600 kg in 1936 and 190,400 kg in 1937. In some locations, over 100,000 crabs were trapped per day (Panning 1939). In 1938, the most densely populated areas were the Elbe

River from the mouth up to Prague, Czechoslovakia, and the coastal regions of Germany and Holland from the Elbe to the Rhine rivers (Panning 1939). The mitten crab population in other countries was reported as sparse (Panning 1939).

Only intermittent collections of the mitten crab have been reported in many countries since the proliferation of the 1930s. After the population declined in the 1940s, only a few crabs are annually collected along the Baltic Sea coast and in freshwater areas (Jazdzewski and Konopacka 1993). In the Seine estuary of France, few crabs were collected. During the 52 years of sampling, from the 1940s to the 1990s, only 60 individuals were reported (Vincent 1996). During the winter of 1963, France experienced a cold spell. Following that winter, no crabs were captured in the Seine estuary until 1975. Although adult crabs can tolerate 0 °C temperatures for up to seven days, the severe weather conditions were probably fatal for the juvenile crabs residing in freshwater (Vincent 1996).

In other areas, such as the Netherlands, periodic localized population explosions occurred (Ingle 1986, J. Mares, Strandwerkgroep, email comm. to K. Webb, USFWS, November 1998). From the mid-1930s to the mid-1950s, the mitten crab was very abundant along the Belgian coast and in coastal streams (Strandwerkgroep 1998). The population declined substantially for unknown reasons and only a few crabs were sighted every year.

Mitten crab abundance is currently increasing in portions of southern Holland, Belgium, England, and Germany, coinciding with an improvement in water quality. In Holland and Belgium, the population increased during the 1990s, with hundreds of crab sightings each year (Strandwerkgroep 1998). During the summer and fall of 1996, eel fisherman reportedly caught more crabs than eels (Strandwerkgroep 1998, J. Mares, Strandwerkgroep, email comm. to K. Webb, USFWS, November 1998).

Since first detected in England, the majority of sightings, although sporadic, were in the River Thames. Long-term fish and macroinvertebrate abundance data has been collected at an intake pump located near the mouth of the River Thames (Attrill and Thomas 1996). According to the data, mitten crab occurrences became more frequent after 1988 (Attrill and Thomas 1996). Crab abundance increased in late 1991 and increased significantly in November 1992 with 32 crabs per 500 million Liters (Attrill and Thomas 1996). During October 1992, hundreds of crabs were captured in the intake tanks of a power station located 45 km upstream of West Thurrock in the River Thames (Attrill and Thomas 1996). The population increase in southeast England estuaries from 1989 to 1992 coincided with a decrease in outflow and an increase in salinity (Attrill and Thomas 1996).

North America

Although only established in California, the mitten crab has been collected in other parts of North America. An adult male was collected in the Detroit River at Windsor, Ontario, in October 1965, and a female and two male adults were collected in Lake Erie in April and May of 1973 (Nepszy and Leach 1973). Another six to seven crabs were collected in the Great Lakes region between 1973 and 1994 (J. Leach, pers. comm. 1994, as cited in Cohen and Carlton 1997). Because the Great Lakes are too fresh for successful egg develop (Cohen and Carlton 1997), mitten crabs were probably transported in ballast water as larvae or introduced as adults. In Louisiana in 1987, an adult was collected in the Mississippi River Delta (D. Felder, pers. comm. 1995, as cited in USFWS 1989).

San Francisco Estuary

The Chinese mitten crab was first collected in south San Francisco Bay by commercial shrimp trawlers in 1992 and was collected in San Pablo Bay in fall 1994 (Hieb 1997). In 1996, a total of 45 mitten crabs were collected from the Sacramento-San Joaquin Delta, Suisun Bay, and Suisun Marsh (Hieb 1997, Veldhuizen 1997). In 1997, an estimated 16,000 to 20,000 mitten crabs were captured in the estuary (USBR unpublished data). In 1998, over one million mitten crabs were collected in the estuary (USBR unpublished data).

As of January 1999, the known distribution of the Chinese mitten crab in California extends north of Delevan National Wildlife Refuge in the Sacramento River drainage, north of Marysville in the Feather River drainage, east of Roseville in the American River drainage, in Littlejohns Creek and Mormon Slough to eastern San Joaquin County near Calaveras County, south in the San Joaquin River drainage near San Luis National Wildlife Refuge, and south in the California Aqueduct near Kettleman City and Taft (Veldhuizen and Hieb 1998b, K. Hieb, CDFG, unpublished data). In addition, the mitten crab is present throughout most tributaries to San Pablo, Suisun, and South bays (Veldhuizen and Hieb 1998b). The mitten crab's potential distribution in the San Francisco Estuary watershed extends throughout all waterways up to any migration barrier, such as large dams.

Other Regions

A Chinese mitten crab was found in Hawaii in the 1950s (Edmondson 1959, as cited in Gollash 1997).

POTENTIAL DISPERSAL MECHANISMS

The Chinese mitten crab may potentially expand its range along the West Coast of North America. The most probable dispersal mechanisms are ocean currents, ballast water transport, and human transport. Planktonic larval mitten crabs may be carried out of the San Francisco Bay to the Pacific Ocean, especially during periods of high outflow, where they potentially could be disbursed by ocean currents to coastal streams and estuaries to the north and south of San Francisco Bay, following a similar disbursement pattern as the European green crab, *Carcinus maenas* (Grosholz and Ruiz 1995). The mitten crab may have been dispersed by ocean currents along the coast of northern Europe (Vincent 1996).

The transport of foreign species in ballast water and their subsequent release to new waters is very common. Ballast water transport is thought to be the introduction mechanism of the mitten crab to Germany, England, the Mississippi River delta, and Lake Erie (Ingle 1986, Peters and Panning 1933, Panning 1939, Nepszy and Leach 1973). It is one of the more probable modes of introduction of the mitten crab to the San Francisco Estuary (Cohen and Carlton 1997). Ships travelling to and from West Coast ports may transport the mitten crab from the San Francisco Estuary to new locations.

Expansion of the crab's range may also be facilitated through human activity, such as deliberate release to establish a local fishery. The developing gonads and meat of the Chinese mitten crab are considered a delicacy. The developing, orange ovaries of the maturing female are prized for their flavor. In China, the mitten crab supports a fishery with an annual catch of over 10,000 tons (Li et al. 1993). The mitten crab has been found in passengers' carry-on luggage at Seattle, San Francisco and Los Angeles international airports and imported live to markets in Los Angeles and San Francisco in California and to cities in New York (Cohen and Carlton 1997, K. Hieb, pers. comm. 1999). In

1986, markets in San Francisco and Los Angeles were selling live crabs for US$27.50 to $32.00 per kg (Cohen and Carlton 1997). In Singapore, the 1996 retail price was $80 to $110 per kg with a total regional demand estimated at $340 million annually (unknown if these price estimates are in US currency) (Synergy 1996). In Bangkok, the going rate was about US$1 per kg several years ago (Andre Cattrijsse, University of Gent, Belgium, email to Ted Frink, CDWR, 1998).

FACTORS EFFECTING ESTABLISHMENT

Although the Chinese mitten crab may be transported to new watersheds, establishment may not occur. The appropriate habitat conditions must be present. However, determining the species' ultimate range on the west coast of North America is problemmatic due to the lack of information on specific physiological requirements and tolerances for all life stages. Below are the findings of one study conducted on larval crabs and other anecdotal information on physiological tolerances.

In a series of laboratory experiments, Anger (1991) determined the salinity and temperature tolerances of each larval stage of *E. sinensis*. For all combinations of constant temperature (6, 9, 12, 15, and 18 °C) and salinity (10‰, 15‰, 20‰, 25‰, and 32‰), Anger found:

- Salinity tolerance ranges: zoeal stage I, 10‰ to 32‰; zoeal stage II, 10‰ to 32‰; zoeal stage III, 10‰ to 32‰; zoeal stage IV, 15‰ to 32‰; zoeal stage V, 15‰ to 32‰; megalopa, ≤5‰ to 32‰. (Note: actual salinity tolerance range is dependent upon temperature.)

- Above 12 °C, successful development from hatching through metamorphosis occurred at most salinities.

- At 6 and 9 °C and at any salinity, all larvae died during the first zoeal stage.

- At 15‰ and 15 °C, high mortality and developmental abnormalities occurred.
- At 10‰, no larvae survived beyond stage I at 15 °C and no lavae survived beyond stage III at 18 °C.
- Zoeal stage I and megalopa suffered high mortality in a combination of 32‰ and temperature ≤15 °C.
- Complete development did not occur in constant salinities of 15‰ and 10‰.
- Survival (lifespan) increased at higher temperatures for all salinities.
- Range of salinity tolerance increased with increasing temperature.
- In general, development time and mortality increased at relatively low and high salinities.

Thus, successful development of larval mitten crabs requires temperatures above 9 °C and access to a range of salinities.

Based on the species current distribution, the Chinese mitten crab can become established in areas with temperature regimes between 10 and 25 °C. Temperatures in the Yellow Sea range from 15 to 25 °C, and the average yearly surface temperature of the North and Baltic seas range from 10 to 15 °C (Williams et al. 1960, as cited in USFWS 1989). In addition, adult mitten crabs can tolerate extremely low temperatures. They can survive in water temp of 0 °C for up to seven days and resume normal activity if placed in warmer water (Vincent 1996). Higher temperatures of 27 to 29 °C is reported as suitable for mitten crab culture in Singapore (Synergy 1996). In tributaries to south San Francisco Bay, juvenile crabs occupied areas with water temperatures of 20 to 31 °C (Halat 1996). Temperature regimes similar to those of the Yellow Sea off the coast of China and Korea and of the North and Baltic seas off the coast of Northern Europe and Scandinavia exist along the coast of North America (Williams et al. 1960, as cited in USFWS 1989). Suitable temperatures occur on the west coast from British Colombia's Queen Charlotte Island to the Baja Peninsula and on the east coast from Nova Scotia to Florida (Williams et al. 1960, as cited in USFWS 1989).

Juvenile and adult Chinese mitten crabs can also survive long periods out of water. Crabs can survive up to 38 days in a wet meadow (Nepszy and Leach 1973) and at least 10 days in a burrow in a dessicating field (CDFG and CDWR unpublished data). Air temperature in the burrow was significantly lower than the ambient air temperature. Thus, the Chinese mitten crab can survive in areas with fluctuating water levels.

IMPACTS OF THE CHINESE MITTEN CRAB IN CALIFORNIA

Based on the impacts of the mitten crab in its native range and in Europe, a large mitten crab population poses several threats to California. These impacts have both ecological and economic consequences. The impacts of the increasing crab population are already evident.

Impacts on Levees

In Germany, the numerous burrows constructed by mitten crabs accelerated bank erosion rates and caused reduced levee stability (Peters and Panning 1933, Panning 1939). In some locations, burrows were reported to be up to 50 cm (20 inches) deep (Peters and Panning 1933). In south San Francisco Bay creeks, mitten crab burrow densities of nearly 30 burrows/m^2 (3 burrows/ft^2) have been reported with most burrows no more than 20 to 30 cm (8 to 12 inches) deep (Halat 1996). Densities in the Sacramento-San Joaquin Delta and Suisun Marsh are currently much lower ($\leq$ 5 crabs/m^2) (Veldhuizen 1997, Holmes and Osmondson 1998), but are expected to increase to levels comparable to south San Francisco Bay creeks within several years.

Based on currently available data, any damage to banks or levees in the estuary should be confined to tidally influenced areas and will be dependent on crab density, levee structure, and suitability of the bank for burrowing. Due to the extensive levee system protecting agricultural fields and communities in the delta, deterioration of levees due to mitten crab burrows is of great concern.

Impacts on Fisheries

The most widely reported economic impact of mitten crabs in Europe was damage to commercial fishing nets and the catch when high numbers of crabs were caught (Panning 1939). The crabs ate the abdomens of the fish and caused increased wear on the nets. Crabs also filled eel-basket pots and hoop nets, preventing eels from entering the traps, thus reducing catch (Panning 1939). In 1981, the mitten crab population in the Netherlands increased substantially, resulting in serious damage to fishing nets (Ingle 1986). However, with the currently low population level in most areas of Europe and a demand for crabs by Chinese restaurants, mitten crabs are no longer a problematic by-catch (C. Schubart, email comm. with K. Hieb, November 17, 1997).

In the San Francisco Estuary, the crab has been a nuisance to commercial bay shrimp trawlers and sport anglers for several years. In south San Francisco Bay, commercial shrimp trawlers find it time consuming to remove crabs from their nets (one fisherman twice caught over 200 crabs in a single tow during fall 1996). They are also concerned that a large catch of mitten crabs will damage their nets and the shrimp. Damaged shrimp are unsuitable for the bait market. Currently, shrimp trawlers are able to move to other areas in south San Francisco Bay with fewer crabs, but this option will diminish as the mitten crab population grows.

A commercial fishery for the introduced signal crayfish (*Pacifastacus leniusculus*) is located in the Sacramento-San Joaquin Delta. During fall 1998, when large numbers of adult mitten crabs migrated downstream, mitten crabs were caught in crayfish traps. If the mitten crab population continues to increase, the crab will become a serious pest by filling the traps and, thus, reducing the crayfish catch. In addition, the mitten crab overlaps in dietary and habitat preferences with the signal crayfish which may reduce crayfish abundance and growth rate.

The sport fishery in the Sacramento-San Joaquin Delta is also impacted by the increasing mitten crab population through loss of bait. The majority of complaints received by CDFG concerning the mitten crab are from recreational anglers.

Water Diversion Impacts

Currently, the most conspicuous impact of the crab in California is on the fish salvage operations at the Federal and State water pumping plants and fish collection facilities in the south delta. These facilities pump and divert several million acre-feet of water from the Sacramento-San Joaquin Delta annually. The fish collection facilities screen all water heading toward the pumping plants and salvage millions of fish.

At the fish facilities, out-migrating adult crabs are entrained along with fish. Only 25 crabs were counted at both the federal Tracy Fish Collection Facility (TFCF) and the State Skinner Fish Facility (SFF) in 1996. In 1997, an estimated 16,000 to 20,000 crabs were captured in the holding tanks at TFCF (USBR unpublished data). In 1998, nearly 1 million crabs were entrained into the federal facility alone (USBR unpublished data). The fish salvage operations at TFCF and SFF were severely hindered by the large numbers of mitten crabs in the holding tanks and fish transport trucks. Initially, crabs were entrained seasonally, mainly during the fall downstream migration period. In 1998, due to the large population size, mitten crabs were entrained year-round with approximately 100 crabs captured per week during the non-migratory periods and 5,000 to 40,000 crabs captured per day during the peak fall migratory period (USBR unpublished data).

In Europe, reports were made of crabs entering water intake pipes or trapped on the screens (Ingle 1986, Attrill and Thomas 1996, Vincent 1996, J. Mares, Strandwerkgroep, email comm. to K. Webb, USFWS, November 1998). In California, Pacific Gas and Electric Company (PG&E) reported the Pittsburg Power Plant, located on the southern shore of Suisun Bay, was affected by high numbers of adults in fall 1997 and 1998, and the Contra Costa Plant, located near Antioch, was affected in fall 1998 (K. Hieb, CDFG, pers. comm. 1998). Workers noticed reduced flows in the cooling water system. Upon back-flushing, they found the internal piping system had been partially blocked by hundreds of crabs.

Agricultural Impacts and Concerns

In its native range in China and Korea, juvenile mitten crabs were reported to damage rice crops by consuming the young rice shoots and burrowing in the rice field levees (Ng 1988, as cited in Halat 1996). Rice fields in tidally influenced areas apparently are most subject to damage. However, no control measures have been reported. In some rice fields, the crab is even cultured with fish. Apparently, the mitten crab is stocked at a rate that does not damage the rice crop.

Ecological Concerns

The ecological impact of a large mitten crab population is the least understood of all the potential impacts. A large population of mitten crabs could change the structure of the estuary's fresh and brackish water benthic invertebrate communities through direct predation and effect the abundance and growth rates of other species through competition. In tributaries to south San Francisco Bay, the mitten crab and the introduced red swamp crayfish (*Procambarus clarkii*) co-occur, overlapping in dietary and habitat preferences. A 1996 survey found no negative correlation between the presence of the mitten crab and presence of the red swamp crayfish in tributaries to south San Francisco Bay; the crayfish was always present in areas with the mitten crab (Halat 1996). However, at almost all sites mitten crabs were visually more abundant, active, and aggressive than crayfish (Halat 1996). If competition does occur, the mitten crab may reduce abundance and growth rates of the red swamp crayfish and the introduced signal crayfish (*Pacifasticus leniusculus*), which supports a commercial fishery in the Sacramento-San Joaquin Delta.

Fish species which produce demersal or adhesive eggs may also be impacted. Chinese mitten crabs may prey on the eggs of nest building species, such as centrarchids. Some fish species spawn in submergent vegetation, a known habitat of mitten crabs, and thus expose their eggs to mitten crab predation. Mitten crabs have the ability to reach salmonid spawning grounds. However, with the cold water temperatures in these areas supressing the crabs' metabolic activity, the predation rate may be low.

Public Health Concerns

The presence of the mitten crab is also a human health concern, as it is a secondary host to the Oriental lung fluke (*Paragonimus westermani*), with mammals, including humans, as the final host. The fluke causes tuberculosis-like or influenza-like symptoms in humans. Humans risk infestation through the consumption of raw or partially cooked infected mitten crabs or the transfer of the crab's bodily fluids through nonsterile cooking practices (USFWS 1989, Marquardt and Demaree 1985, as cited in Halat 1996). Neither the lung fluke nor any of the freshwater snail species that serve as the primary intermediate host for the fluke in Asia have been found in the estuary. It has been noted that several species of freshwater snails currently present in the watershed could possibly serve as an intermediate host or that the correct snail species is present but yet undetected (USFWS 1989).

Mitten crabs are known to inhabitat agricultural ditches and other areas that may contain high levels of contaminants. The crabs potentially could bioaccumulate contaminants, which then would be transferred to predators, such as sturgeon, and to humans.

Alternative 2 would: 1) be low cost in terms of additional funds, as money is already being set aside for the screen's construction, operational testing, and research of its efficiency in collecting crabs and minimizing impacts on fish salvage; 2) require 1-2 additional people to maintain it; 3) *have relatively low fish salvage risk and; 4) *have low water supply risk; 5) can be installed prior to the next crab migration; 6) be good for public relations as it shows that we have been working on a TWS solution since September, 1998; 7) have a high crab elimination efficiency; 8) require a study design and report, and alteration of our 1992/1998 salvage Agreement with DFG;

POPULATION CONTROL MEASURES

In Germany, extensive efforts were undertaken by the government in the 1920s and the 1930s to control mitten crab populations in some rivers (Panning 1939). Control measures often took advantage of the mitten crab's migratory behavior. When the crabs reached a barrier, such as a weir or small dam, their upstream migration slowed and they congregrated in large numbers below the obstruction. The crabs attempted to bypass the obstruction by climbing over the barrier or climbing up the banks. A variety of trapping methods were used to capture the crabs as they attempted to circumvent the structure (see Peters and Hoppe 1938 and Panning 1939). In some locations, traps were placed on the upstream side of dams and captured juvenile crabs as they migrated upstream, climbed over the dam, and fell into the traps. In other locations, troughs where constructed at the top of the levee and the crabs were funneled toward them. The crabs fell into the troughs and could not escape; the troughs were tiled to prevent the crabs from climbing out. Barrels, wrapped with wire netting or canvas, were also placed below dams amongst the congregrating crabs. The crabs would climb up the barrels and fall inside. At one trapping site, over 113,000 crabs were captured in a single day (Panning 1939). Electrical screens were also installed on the river bottom. Frequencies of 30 to 40 pulses per minute were found to disable and then kill the crabs (Halsband 1968, as cited in USFWS 1989).

It is unknown whether these control efforts were successful at controlling the population, as literature is very scare. The population did decline in the late 1940s, coinciding with increasing water pollution. One hypothesis for the decline of mitten crabs is the increasing water pollution reduced prey abundance (Gollash 1999). Increasing water pollution is attributed to the decline of the mitten crab in other locations, also (Vincent 1996).

Alternative 3. Travelling Water Screen (TWS) with Reduced Pumping.

Actions under Alternative 3 would be the same as Alternative 2, except that it would also entail reductions in pumping to aid the TWS and other TFCF operations. Reduced pumping would entrain fewer crabs into the TFCF and require less manpower to handle them. The TWS and other operations could then better able to keep pace with the fewer crabs showing up. However, reduced pumping means less water being pumped during this time of the year and the lost water would probably have to be made up some how. We don't expect this to be a popular alternative within our agency or amongst the water user community.

REFERENCES

Anger, K. 1991. Effects of temperature and salinity on the larval development of the Chinese mitten crab *Eriocheir sinensis* (Decapoda: Grapsidae). Marine Ecology Progress Series 72:103-110.

Attrill, M. J. and R. M. Thomas. 1996. Long-term distribution patterns of mobile estuarine invertebrates (Ctenophora, Cnidaria, Crustacea: Decapoda) in relation to hydrological parameters. Marine Ecology Progress Series 143:25-36.

Cohen, A. N. and J. T. Carlton. 1995. Biological study. Nonindigenous aquatic species in a United States estuary: a case study of the biological invasions of the San Francisco Bay and Delta. United States Fish and Wildlife Service, Washington, D. C., and National Sea Grant College Program, Connecticut Sea Grant, NTIS report no. PB96-1666525.

Cohen, A. N. and J. T. Carlton. 1997. Transoceanic transport mechanisms: introduction of the Chinese mitten crab, *Eriocheir sinensis*, to California. Pacific Science 51:1-11.

Edmondson, C. H. 1959. Hawaiian Grapsidae. Occ. Pap. Bernice P. Bishop Mus. Honolulu, Hawaii 22(10):153-202.

Gollash, S. 1999. Current status on the increasing abundance of the Chinese mitten crab *Eriocheir sinensis* in the German Elbe River. Abstract submitted to United States Fish and Wildlife Service, 6 pp.

Grosholz, E. D., and G. M. Ruiz. 1995. Spread and potential impact of the recently introduced European green crab, *Carcinus maenas*, in central California. Marine Biology 122:239-247.

Halat, K. M. 1996. The distribution and abundance of the Chinese mitten crab (*Eriocheir sinensis*) in southern San Francisco Bay, 1995-1996. M.S. Thesis, University of California, Berkeley, 80 pp.

Hieb, K. 1997. Chinese mitten crabs in the delta. IEP Newsletter 10(1):14-15.

Hinrichs, and K. G. Grell. 1973. Entwicklungsstadien von *Eriocheir sinensis*, H. Milne Edwards, im helgolander plankton. Zool. Anz. 119:217-221.

Hoestlandt, H. 1948. Recherches sur la biologie de l'*Eriocheir sinensis* H. Milne-Edwards (Crustace brachyoure). Annales de l'Institut Oceanographique 24(1):1-116.

Hoestlandt, H. 1959. Repartition actuelle du crabe Chinois. Bulletin Francaise Pisciculture 194:1-13.

Holmes, A. and J. Osmondson. 1998. The second annual IEP monitoring survey of the Chinese mitten crab in the Sacramento-San Joaquin Delta and Suisun Marsh. IEP Newsletter 12(1):24-27.

USFWS (United States Fish and Wildlife Service). 1989. Importation or shipment of injurious wildlife: mitten crabs. Federal Register 54(98):22286-22289.

Ingle, R. W. 1980. British crabs. pp. 123-124.

Ingle, R. W. 1986. The Chinese mitten crab *Eriocheir sinensis* H. Milne Edwards – a contentious immigrant. The London Naturalist 65:101-105.

Jazdzewski, K. and A. Konopacka. 1993. Survey and distribution of crustacea malacostraca in Poland. Crustaceana 65(2):177-191.

Kaestner, A. 1970. Invertebrate zoology. III. Crustacea. John Wiley and Sons, Inc., New York, N. Y. 523 p.

Kim, C. H. and S. G. Hwang. 1995. The complete larval development of the mitten crab, *Eriocheir sinensis* H. Milne Edwards, 1853 (Decapoda, Brachyura, Grapsidae) reared in the laboratory and a key to the known zoeae of the Varuninae. Crustaceana 68(7):793-812.

Li, G., Q. Shen, and Z. Xu. 1993. Morphometric and biochemical genetic variation of the mitten crab, *Eriocheir*, in southern China. Aquaculture 111:103-115.

Marquardt, W. C. and R. S. Demaree. 1985. Parasitology. MacMillan Publishing. New York. p. 274.

Nepszy, S. J. and J. H. Leach. 1973. First records of the Chinese mitten crab, *Eriocheir sinensis*, (Crustacea: Brachyura) from North America. Journal of Fisheries Research Board of Canada 30: 1909-1910.

Ng, P. K. L. 1988. The fresh water crabs of pennisular Malaysia and Singapore. Shing Lee Publishers PTE Ltd., Singapore.

Panning, A. 1939. The Chinese mitten crab. Annual Report Smithsonian Institution, 1938, pp. 361-375.

Pape, A. 1939. Untersuchungen zur biologie und schadwirkung des wollhandkrabbe in binnensien. Z. Fisch. Hilfswiss. 37:699-714.

Peters, N. 1938. Ausbreitung und verbreitung der Chinesischen wollhandkrabbe (*Eriocheir sinensis* M. Edw.) in Europa in den jahren 1933 bis 1935. Mitteilungen aus dem Hamburgischen Zoologischen Museum und Institut, Hamburg 47:1-31.

Peters, N. and H. Hoppe. 1938. Uber begampfung und verwerung der wollhandkrabbe. Mitteilungen aus dem Hamburgischen Zoologischen Museum und Institut, Hamburg 47:140-171.

Peters, N. and A. Panning. 1933. Die Chinesische wollhandkrabbe (*Eriocheir sinensis* H. Milne-Edwards) in Deutschland. Zoologischer Anzeiger Supplement 104:1-180.

Sandifer, P. A. and T. I. J. Smith. 1979. Possible significance of variation in the larval development of palaemonid shrimp. Journal of Experimental Marine Biology and Ecology 39:55-64.

Strandwerkgroep. 1998. http://www.ping.be/tadorna/index.shtml.

Synergy. 1996. http://www.nstb.gov.sg/whatsnew/synergy/supp_jun96/8.html.

Tan, Q. K. et al. 1984. The ecological study on the anadromous crab *Eriocheir sinensis* going upstream. Tung wu hsueh tsa chih (Chinese Journal of Zoology) 6:19-22.

Thiel, H. 1938. Die allgemeinen Ernährungsgrundlagen der chinesischen Wollhandkrabbe (*Eriocheir sinensis* Milne-Edwards) in Deutschland, insbesondere im Einwanderungsgebiet im weiteren Sinne. Mitt. aus dem Hamb. Zool. Mus. & Inst. in Hamburg 47:50-64.

Veldhuizen, T. 1997. First annual IEP monitoring survey of the Chinese mitten crab in the delta and Suisun Marsh. IEP Newsletter 10(4):21-22.

Veldhuizen, T. and K. Hieb. 1998a. What difference can one crab species make? The ongoing tale of the Chinese mitten crab and the San Francisco Estuary. Outdoor California 59(3):19-21.

Veldhuizen, T. and K. Hieb. 1998b. What's new on the mitten crab front? IEP Newsletter 11(3):43.

Vincent, T. 1996. Le crabe Chinois *Eriocheir sinensis* H. Milne-Edwards 1854 (Crustacea, Brachyura) en Seine-maritime, France. Annales de l'Institut Oceanographic 72(2):155-171.

Wolff, W. J. and A. J. J. Sandee. 1971. Decapoda reptantia. Netherlands Journal of Sea Research 5(2):197-226.

Appendix B
Summary of the Workshop Recommendations

The Mitten Crab Workshop held on March 23, 1999 in Sacramento, California provided a forum to learn about the crab and develop recommendations for the National Management Plan. As mentioned earlier, the break-out groups explored the four subject areas of:

- *Preventing Spread
- *Detection and Monitoring
- *Reducing Impacts
- *Controlling Populations

Participants developed outlines of their discussions and facilitators presented the results to the gathering. The following is a summary of the work group outlines.

Objective A. **Prevent Spread**

Strategy 1. Identify natural and human-assisted pathways of spread
- a) Ballast water/hull fouling
- b) Human transport/releases
- c) Ocean currents
- d) Dredging
- e) Recreational/commercial boat equipment

Strategy 2. Reduce risk of human-assisted spread
- a) Enhance enforcement of possession and transportation prohibitions
- b) Develop/implement education and outreach program to provide information about regulations, enforcement efforts, penalties and negative impacts.
- c) Encourage development of comparable/compatible regulations, enforcement and education programs for states, provinces, and drainage basins at risk
- d) Support efforts to restrict the transfer of crabs via ballast water releases
- e) Identify areas of large populations and support ban of ballast water uptake in these areas
- f) Develop larval identification techniques

Objective B. **Promptly Detect New Populations and Monitor Status and Impacts of Known Populations.**

Strategy 1. Monitor status and impacts of known populations
- a) Develop standard sampling methods and protocols
  - Important considerations include: bycatch, impacts to other species, nocturnal behavior.
  - Suggested methods: traps, trawls, seines, snorkel surveys, settling plates
- b) Develop and implement a cooperative monitoring program for the San Francisco Estuary and Central Valley which includes state and federal facilities data, commercial fisherman, volunteers, and existing monitoring programs.

Strategy 2. Establish detection and monitoring programs for other areas at risk
- a) Use standard methods and protocols developed for the Bay-Delta to initiate a detection and monitoring program for

West coast (WA, OR, BC, Columbia River basin)
Mississippi River
New York and other areas at risk

Objective C. **Reduce negative impacts**

Strategy 1. Develop understanding of negative impacts on ecology, levees and agriculture
  a) Improve understanding of biology, life history, environmental tolerances, critical habitats of mitten crabs, and species at risk from mitten crabs
  b) Monitor/evaluate impacts to agriculture (education and outreach to farmers)
  c) Monitor/evaluate impacts to levees (education and outreach to levee maintenance districts)
  d) Evaluate current and potential impacts to recovery and restoration efforts (e.g., ESA listed species)
Strategy 2. If warranted, develop methods to reduce impacts
  a) Assess exclusionary measures such as traps and barriers
  b) Assess preferred slopes, soil types, etc.
  C) Assess reducing local populations through environment modifications
Strategy 3. Develop program to manage populations at state, federal and NGO fish facilities to reduce impacts on fish salvage, fish passage and water diversion operations.
  a) Identify and evaluate measures to keep crabs out of facilities and industry
  b) Identify and evaluate measures to remove crabs from inside facilities and plants
  c) Identify water management constraints
  d) Identify value of modifications of South Delta barriers
Strategy 4. Evaluate potential beneficial uses for crab
  a) Evaluate value for Human consumption, Feed, Fertilizer, Bait
  b) Identify public health concerns
    1) Investigate presence of lung fluke hosts
    2) Investigate contaminant loads and potential risks

Objective D. **Develop strategies for Population Control**

Strategy 1. Evaluate potential control methods that take advantage of biology and life history and possible impacts (by-catch, listed species, recreation, etc)
  a) Improve understanding of biology and life history, migratory behavior, recruitment dynamics, reproductive biology, feeding ecology.
  b) Evaluate value, risks and impacts of trapping, fishing, etc.
  c) Evaluate the value, risks, options and impacts of a commercial harvest
  d) Evaluate the value, risks, options and impacts of a contract fishery
  e) Evaluate the value, risks, options and impacts of sport fishery
Strategy 2. Evaluate control methods that utilize other technologies
  a) Chemical
  b) Biological- Genetic parasitic castrator, viruses, pheromones, sterilization

APPENDIX C

Management Alternatives for the Tracy Office (Bureau of Reclamation), in Anticipation of Further Detrimental Impacts by Chinese Mitten Crabs Upon Fish Salvage Operations at the Tracy Fish Collection Facility (TFCF),

Executive Summary

Starting in September, 1998, Chinese mitten crabs began to migrate to the TFCF in such high numbers that they clogged many of the fish salvage features. This resulted in the deaths of thousands of fish that would have been salvaged under normal operations. To successfully salvage fish, it became imperative to separate them from crabs. Mechanical crab removal or separation efforts were undertaken in the secondary channel and holding tanks and included trapping, dipping, and screening. Captured crabs were buried and killed off-site.

The 1998 migration of crabs through TFCF was a learning experience (Figures 1-6). Because we monitored crabs as bycatch in bi-hourly fish counts and evaluated our attempts crab removal, we estimated that at least 750,000 were likely to have come through the TFCF in September to November of 1998, most moved in at night, and more were males than females. Furthermore, our attempts at removing crabs, while not successful at first, indicated that crabs move along the bottom and sides of channels and are poor swimmers.

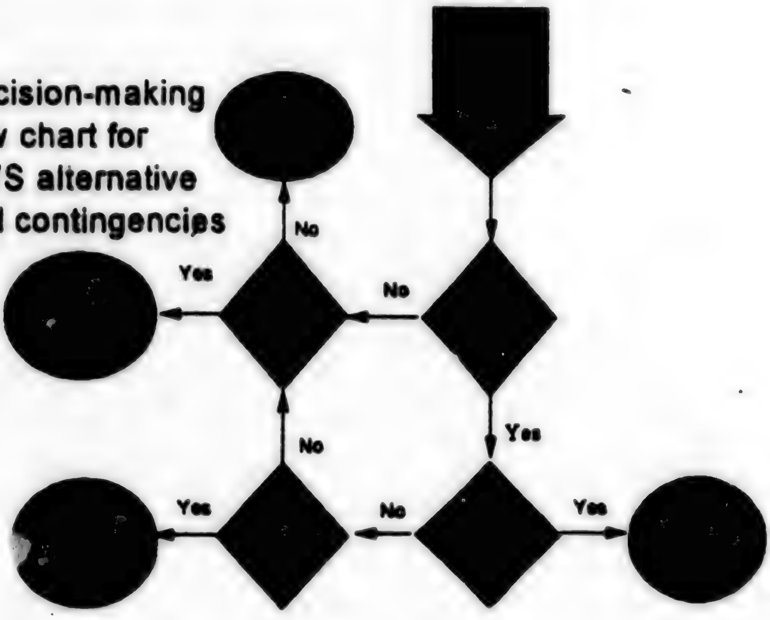
Crab removal efforts were mainly reactionary, and in some cases, experimental. The method that showed the most promise was a scaled down version of a travelling water screen (TWS), which removed over 80% of crabs from the water column in the secondaries. Laboratory testing of appropriately scaled models at Reclamation's Technical Services Center (TSC) in Denver have removed an even higher percentage.

After developing and discussing a number of alternatives, as outlined in the Mitten Crab Management Plan (attached), Reclamation has decided to select as its preferred alternative a "combination" alternative, which entails the TWS as its centerpiece. Other actions produced 16 alternatives, often in various combinations, and included joint point of diversion, lifting of louvers to let crabs pass the TFCF, removal of crabs outside of the TFCF, crab removal by fish friendly pumps to above ground pools, and restricted pumping.

Comments from specialists from all but one of the appropriate regulatory agencies have been gathered and incorporated into the main body of the recent draft of the crab management plan. We realize that if the TWS does not work effectively, then immediate coordination and consultation will take place with the other resource agencies, stakeholders, and within Reclamation to determine alternative courses of action (contingency plans, in attached flow chart). It is our hope that these contingency actions and their criteria for activation will be sanctioned well in advance of their being needed. Since informal review is near completion, we would like to take the next step of gaining official approval, in writing. This may entail entering into an "Agreement", or MOU.

If the TWS is found to exert unacceptable impacts upon the fish (as determined by Tracy Office Management as well as by regulatory agencies), then we will pursue joint point of diversion with SWP. If this is not possible, we will have to either stop pumping or continue, facing the consequences.

If the TWS exerts acceptable impacts upon the fish and works well, it will be the sole chosen method of crab control.



Decision-making flow chart for TWS alternative and contingencies

If the impacts are acceptable, but the TWS is not keeping pace with an overabundance of crabs, then the option of also lifting louvers will be considered. If this is an option, then crabs will be removed from the DMC at the Byron Road siphon. If this is not an option, we will consider joint point of diversion.

If joint point is not an option, we will either stop pumping or continue, facing the consequences. Comments from appropriate regulatory agency specialists have been gathered and incorporated into the main body of the recent draft of the crab management plan.

In summary, there are at least five possible actions: 1) Sole TWS implementation; 2) joint point of diversion; 3) lift louvers and use TWS; 4) cease pumping; or 5) continue pumping, with consequences (management will have to help me determine what we think the consequences will be). It may be possible that at any time any combination of these actions may be chosen as we feel appropriate. Aggressive monitoring and mitigation programs will be assured as complications with endangered or other special status species are possible.

Management Alternatives for the Tracy Office (Bureau of Reclamation), in Anticipation of Further Detrimental Impacts by Chinese Mitten Crabs Upon Fish Salvage Operations at the Tracy Fish Collection Facility (TFCF).

Introduction

Mitten Crab Overabundance

There has been an exponential increase in Chinese mitten crabs entrained through the Tracy Fish Collection Facility (TFCF) since they were first collected there in September, 1996. These catadramous crabs have expanded their range from the San Francisco Bay into the Delta. They are drawn on their annual seaward breeding migration to CVP export flows pumped through the TFCF. Their numbers entrained at the TFCF increased from mere dozens in 1996 to over 30,000 in 1997, to over 775,000 in 1998, a 25 fold increase over the last two years. Of the crabs entrained through the TFCF in 1998, over 500,000 were extrapolated from ten-minute fish counts (subsampling) and over 275,000 were estimated to have been removed by trapping. Over 90% were collected in September and October (Figure 1). The start of peaks in 1997 and 1998 coincided closely with the onset of cooler water temperatures (Figures 2 and 3).

As the numbers and range of mitten crabs has increased, so has the length of time over which they are collected. Now they are captured nearly year-round. The majority entrained have been males (Figure 4), travelling at night (Figure 5). Trapping efforts at TFCF indicate that they primarily move along the bottom of the channel. If the crabs continue to increase at the present rate and south Delta barriers are not in place, as many as 20 million may migrate to the TFCF in September and October, 1999.

Crab Removal Efforts

Starting in September, 1998, the mitten crabs began to migrate to the TFCF in such high numbers that they clogged many of the fish salvage features. This resulted in the deaths of thousands of fish that would have been salvaged under normal operations. To successfully salvage fish, it became imperative to separate them from crabs. Mechanical crab removal or separation efforts were undertaken in the secondary channel and holding tanks and included trapping, dipping, and screening. Captured crabs were buried and killed off-site.

A crab trap with numerous additional modifications was constructed and placed in the secondary channel. Modifications included adding baffles and a funnel, adding a pump, and finally adding a deflector (Figure 6). Each was periodically subjected to lifting currents which lowered the traps' efficiency, and revealed the crabs' habit of moving along the bottom of the channel. The crab trap's removal efficiency was near 60% when it rested on the bottom but near zero percent when currents lifted it off the bottom (***Appendix A***). When the trap was modified, its efficiency was similar but ranged widely as it was still subjected to lifting currents. Traps were only effic when maintained properly, which required extensive effort.

The effects of crab trapping on fish salvage were not well quantified but numerous qualitative observations were made. White catfish, yellowfin gobies, and other bottom dwelling fish species were captured in traps (direct loss) while few or none of the midwater or pelagic fish species were captured ***(Appendix B)***. Indirect loss due to the traps' interference with salvage "criteria" flows could not be determined from the limited testing.

Fish salvage operations in the collect tanks were modified concurrent with trap testing in the secondary channel in order to salvage as many fish as possible. Changes included drawing down the water in the collect tanks at a different rate and lowering the collect tank screen in order to separate crabs from fish. The fish were then loaded into the fish haul trucks for release back into the Delta and the crabs into a dump truck for disposal in the spoils area. This procedure proved effective but lengthened the salvage effort ***and still killed and/or missed an undetermined and possibly significant number of fish.***

Another method of separating crabs from fish, called "dipping", was implemented into the modified salvage procedure. This entailed dipnetting fish from 500 gallon buckets used to load fish in transport trucks. This apparently worked quite well for separating pelagic and midwater fish from crabs. The procedure's effect on bottom dwelling fish was detrimental as these fish were killed along with whatever crabs made it this far. Further testing of trapping and dipping efforts was abandoned when they were deemed inefficient.

Another effort involved using a travelling screen originally designed for removing debris in the secondary channel lab model located at Reclamation's Denver Technical Reseach Center (TSC) was tried and tested for filtering mitten crabs from salvage operations. This modular unit fit within the 8 ft wide channel but did not occupy its entire height. The screen was operated for 6 days, showing it was at least 80% efficient under most conditions ***(Appendix C)***. TSC engineers believe that with improvements to better fit the TFCF secondaries, it could remove over 90% of the crabs. Plans are under way to have a full-sized unit built and installed to the TFCF secondaries before the mitten crab migration in 1999.

Alternatives

Alternative Development

Reclamation is concerned that next year's mitten crab invasion will overpower the salvage operations at the TFCF and has charged the Tracy Office with formulating management alternatives for dealing with the anticipated invasion. Dealing with the mitten crab invasion will be exacerbated by the potential removal of south Delta barriers on October 1, 1999, and subsequent onslaught of debris. The Tracy Office's Fish Facility Branch is drawing upon their experience with the biological, mechanical, and operational aspects of mitten crab control to develop alternatives for dealing with them. The following is a discussion of the considerations used by the Fish Facility Branch for developing the alternatives.

Note: Alternatives take into account that Chinese mitten crabs will most likely arrive in the vicinity of TFCF sometime in September or October, 1999, at around the time that temperatures in the Delta begin to drop noticeably. Most mitten crabs move at night and primarily along the bottom and sides of waterways. Close coordination with the Interagency Ecological Program (IEP) is needed in order to track the crabs and water temperatures in order to best be prepared for their arrival.

General Explanation of Alternatives and Comparisons Between Them

Fourteen alternatives were developed at a brainstorming session involving Fish Facility Branch personnel. The alternatives included a No Action alternative (i.e. no change from existing operations), utilization of the travelling water screen, lifting the louvers, crab removals from the intake channel or at south Delta barriers or within the TFCF, re-operation or reductions in pumping through the TFCF, nonstructural barriers, trashrack alteration, or a combination thereof.

Since the last draft of this documents, we have added options for joint point of diversion as negotiated between Reclamation and DWR. DFG comments (Appendix D) indicate that such an arrangement "would allow the SWP/DWR to possibly do make-up pumping at the same time the CVP is curtailing for mitten crabs, thereby negating any net reduction in CVP diversions. This may be possible throughout much of the mitten crab season at the TFCF...". This is possible because the SWP has not experienced the same impacts at the same time as the CVP, and may not do so in 1999, either. Joint Point of Diversion is an option which applies to all alternatives that include reduced pumping. Another additional option is the testing of the fish friendly pumps to above ground tanks as a system for pumping and separating crabs from salvage. This would only be initiated on an evaluative basis.

Criteria for analyzing alternatives were: 1) financial cost; 2) additional manpower required; 3) risk to fish salvage; 4) risk to water supply (exports); 5) whether or not the alternative can be implemented in time for the 1999 crab migration; 6) public relations value; 7) crab elimination efficiency; 8) required permits and environmental documentation; and 9) whether or not it is anticipated that stakeholders will buyoff on the alternative. Analyzing alternatives was completed through comparisons and is outlined in ***Appendix E***. The assumptions underying all alternatives are: 1) that in 1999 more crabs will be entrained through the TFCF than in 1998; 2) south Delta barriers will remain in place until October 1 (Reclamation is in the process of reviewing the possibility of leaving south Delta barriers in place until the crabs have migrated out of the Delta); and 3) crabs will be removed from Tracy Office property and handled by contractors as specified under contract.

Alternative 1. No Action.

If mitten crab numbers continue to increase exponentially, they will exceed the TFCF's ability to handle them, especially if south Delta barriers are removed at the same time. ***As of late Spring 1999, the barriers had not been placed, so debris will still be a problem, but not in uncontrollable amounts. The impacts will be much like in 1998, when barriers were not in place. While debris will not be released all at once, crabs will be allowed to migrate to the TFCF. If they arrive in far greater numbers than in 1998, continuous cleaning may be necessary. Extensive cleaning will be required on primary and secondary louvers as well. If they pass through the secondaries, they will again clog the holding tanks, 500 gallon loadout buckets, release pipes in the trucks, and pipes at release sites. In 1998, when thousands of crabs were allowed into some truckloads, most fish died in hauls to release sites. The situation would likely happen again in 1999 under the "No Action" alternative.***

The No Action alternative would: 1) be low cost until we are forced into another alternative, ultimately at a higher cost; 2) require at least 2 additional people to handle crab separation operations at the TFCF; 3) have maximum risk to fish salvage as crabs would clog TFCF fish salvage features and most fish would die; 4) have high risk to water supply as pumping may be halted until effective fish salvage can be assured; 5) be implementable by the time the crabs arrive; 6) have minimal public relations value as it would show neither the creativity nor preparation expected of us by other agencies, the public, or our stakeholders; 7) have a minimal crab elimination efficiency as many would still be released back to the Delta; 8) would not require permits or environmental documentation; and 9) *would not be expected to obtain buyoff from our stakeholders.

****NMFS comments on the No Action alternative indicate that the mitten crab's adverse impacts on fish collection and handling have the potential to require cessation of pumping should listed species be present. We do not anticipate any NMFS-regulated species being present. We do, however, expect splittail to be present in the vicinity of the TFCF and do not expect to get buyoff from USFWS for the same reasons that NMFS voiced their concerns above (high mortality in salvage attempts).***

****San Luis Delta-Mendota Water Authority (Authority) comment that they do not find the No Action to be a viable alternative (Appendix F).***

Alternative 2. The Travelling Water Screen (TWS) with minor operational changes.

The TWS showed the most promise last year as far as removing crabs from the TFCF bypass system. TSC engineers believe they can provide a model which could remove over 90% of crabs. Presently, they are working on researching the model's effects on fish salvage at their Denver laboratory. Plans are also under way to have a full-sized unit built and installed to the TFCF secondary channel by August, 1999 for full testing. This alternative would have the screen left in the secondary portionof the bypass system for the duration of the crab migration.

Alternative 2 would: 1) be low cost in terms of additional funds, as money is already being set aside for the screen's construction, operational testing, and research of its efficiency in collecting crabs and minimizing impacts on fish salvage; 2) require 1-2 additional people to maintain it; 3) *have relatively low fish salvage risk and; 4) *have low water supply risk; 5) can be installed prior to the next crab migration; 6) be good for public relations as it shows that we have been working on a TWS solution since September, 1998; 7) have a high crab elimination efficiency; 8) require a study design and report, and alteration of our 1992/1998 salvage Agreement with DFG; and 9)** ***be expected to receive buyoff from all stakeholders.***

*Note: This alternatives assumes the TWS will operate proficiently without complications or shutdown. Since a TWS of this size has not been tried over an extended period of time within the secondary channel then it can't be stated with any reason of certainty, other than limited testing at the TSC lab and at the TFCF, whether or not complications will arise. In the event that complications do arise resulting in ineffective or non-use of the TWS, then other arrangements will need to be made in order to handle the mitten crabs. These other arrangements could result in increased risk factors towards fish salvage and water supply operations.

*****Note regarding alternatives 3, 6, 6a, 7, and 7a, all of which incorporate use of the TWS: According to DFG comments (Appendix D), more intensive, and quantified studies (both before and after installation and implementation) of the TWS, investigating its impacts upon salvage efficiency and hydraulics, would need to be carried out. Results of these studies would be used to quantify salvage, loss and take under T&E Species Biological Opinions, especially if splittail and some Spring-run chinook salmon are present. If Reclamation cannot quantify these effects, there is a chance that NMFS and USFWS might derive more conservative ways of estimating a take penalty to be imposed on top of salvage estimates made during the time period of TWS operation.***

*****NMFS comments (Appendix E) state that if fish are present and the TWS does not work, they will not have much disretion to stand by and watch substantial "takings" of fishes they are charged with protecting under ESA, which may include proposed listings for Central Valley fall and late-fall chinook scheduled for decisions in September of 1999. Any take level, depending on its severity, has the potential to halt pumping.***

*****NMFS has voiced no objections to trying the TWS, deferring critical evaluation until it has been tried and debugged, and its effects, both good and bad, evaluated by NMFS. They want it removed when no longer needed. USFWS has not yet responded and is being pursued as a participant in this process.***

*****Authority finds this, and all others with TWS and without lifting of louvers or pumping reductions, to be viable alternatives and will assist in the maintenance and installation, as a partner to Reclamation, which is funding it (Appendix F).***

May 20, 1999

Alternative 3. Travelling Water Screen (TWS) with Reduced Pumping.

Actions under Alternative 3 would be the same as Alternative 2, except that it would also entail reductions in pumping to aid the TWS and other TFCF operations. Reduced pumping would entrain fewer crabs into the TFCF and require less manpower to handle them. The TWS and other operations could then better able to keep pace with the fewer crabs showing up. However, reduced pumping means less water being pumped during this time of the year and the lost water would probably have to be made up some how. We don't expect this to be a popular alternative within our agency or amongst the water user communty.

Alternative 4. Lifting the Louvers (only) to allow crabs to pass through the TFCF.

This management alternative proposes to alter salvage operations by lifting the primary louvers high enough to let the crabs pass along the bottom (6 inches), allow most topwater and midwater fish to enter into the bypass system, and allow much of the debris and bottom dwelling fish to flow on down to the Tracy Pumping Plant (TPP). Reclamation would probably be required to mitigate for fish lost from the Delta to the DMC. One big negative impact from this alternative would be the influx of crabs and debris showing up at the TPP and subsequently into the Delta Mendota Canal (DMC).

Actions under Alternative 4 would: 1) be mid-range in cost, as operational costs would be negiligible, but costs for mitigating the loss of bottomfish could be incurred; 2) no additional people would need to be hired, but an increase in incidental assistance would be required of existing personnel; 3) fish salvage risk would be quite high for bottom fish, as they would be lost under lifted louvers; 4)* high risk to water supply, as the potential for conflict exists between resource agencies' directives for fish salvage in violation of existing agreements; 5) be implementable by the time crabs arrive at the TFCF; 6) have low public relations value. Although we would demonstrate an effective way to separate crabs from our salvage, we would be losing many fish to the DMC, which would be unpopular with much of the public and with resource agencies. ; 7) crab elimination efficiency would be mid-range as it would be high for the TFCF but low for the TPP & DMC; 8) require NEPA documentation and a rewriting of the existing 1992/1998 Agreement for operations of the TFCF to allow for operational changes and mitigation for lost fish; and rewriting of the existing 1992/1998 Agreement for operations of the TFCF to allow for operational changes and mitigation for lost fish; and 9)** not be expected to obtain stakeholder buyoff from the environmental community or resource agencies because of fish lost under louvers. Furthermore, it is expected that water users' would be concerned that the additional crabs conveyed into the DMC would threaten the integrity of the pumps, turnouts, and other structures, and that mitten crabs could eat their crops and burrow into levees and banks.

****Authority believes there is too much risk to the water districts if louvers are lifted and crabs end up pumped into the DMC (Appendix F).***

*****Alternatives which entail the lifting of louvers (4,5,6,7,7a) have DFG and NMFS concerned. The former's concerns center on their not agreeing to our assumption that predominantly bottom fish would be lost and that lifting the louvers alters our salvage estimation process by removing much of the louvering process itself. DFG was not aware that we are only suggesting a six inch lifting. NMFS (comments, Appendix E) neither accepted nor rejected louver lifting, but stated that if it were employed, they might re-evaluate Reclamation's allowed incidental take to account for additional unscreened area. Reclamation believes they can allow 99% of crabs under the louvers, and keep 99% of splittail, salmon, steelhead, and smelt from doing the same. The only special status species they anticiapte impacting is the white sturgeon, and those occur in very low numbers. They will monitor the event if it takes place and might do preliminary tests by lifting the secondaries 6 inches and testing crab and special status fish species entrainment there. Reclamation will mitigate any impacts that they determine to exert.***

Alternative 5. Lift Louvers to allow crabs to pass through and remove crabs from the intake channel before they reach TPP and points downstream in the DMC.

This alternative would be basically the same as Alternative 4 except that crabs would be removed from the intake channel prior to reaching the TPP. Either Reclamation or a contractor service could perform the removal procedure. If a contractor performed the procedure, then the removal method would have to be approved by Reclamation and within IEP guidelines. Methods could include nets or traps set in the intake channel or at the outflow of the Byron Road siphon. Either location would allow for room to operate without impacting watercraft travel, as none is permitted within the DMC, and would only require land use permission from Reclamation. If contracted out, the contracting process could be extensive, complicated, and time-consuming, as much of the technology will be new and untested. The quality and quanitity of potential contractors could improve in the future if crabs are approved for harvesting and marketing.

Actions under Alternative 5 would: 1) be higher cost than just lifting the primary louvers by themselves. (Cost of removing crabs from the intake channel is unknown at this time.); 2) require at least one additional person to monitor and assist in the crab removal contract; 3) risk fish salvage the same as with lifting louvers by themselves but be a greater risk than alternatives utilizing the TWS; 4)*risk water supply less than Alternative 4 because crabs would be removed from TPP and points downstream in the DMC, but be greater than alternatives 2 and 3 because it is less acceptable than the TWS concept to resource agencies; 5) be doubtful that a contract could be let in time for the crab migration in 1999; 6) be much better for public relations than Alternative 4 as crabs would not only be removed from the TFCF, but would entail collecting crabs prior to reaching the TPP; however, it would not be as good for public relations as TWS alternatives 2 and 3 because bottomfish would most likely be lost; 7) have a crab elimination efficiency higher than alternative 4, but less than TWS alternatives 2 and 3 because crabs will still enter the TFCF bypass system anyway; 8) require NEPA, complex contracting, and rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish; and 9) probably not obtain stakeholder buyoff from the environmental community or resource agencies because of fish lost under louvers ***unless they are mitigated for or covered in incidental take.***

****Authority believes this alternative would require more testing and trial methods to ensure that crabs are removed prior to the intake of the pumps, but may be an option for next year. Otherwise, there is too much risk to the water districts if crabs are pumped into the DMC (Appendix F).***

Alternative 5a. Lift Louvers to allow crabs to pass through. Remove crabs from the intake channel before they reach TPP and points downstream in the DMC, and Reductions in Pumping.

This alternative would be basically the same as Alternative 5 except that pumping would be reduced to reduce the number of crabs entrained through the TFCF. This would allow TFCF operators to keep pace with the increased workload volume and complexity.

Alternative 5a would: 1) cost slightly more than alternatives 4 and 5, in terms of lost water, unless the lost water is made up elsewhere, and also considerably more than TWS alternatives 2 and 3 which will remove most crabs at minimal cost; 2) require fewer than the one additional manpower in 5 and the one or more in TWS alternatives 2 and 3; 3) be less fish salvage risk than 5 as reduced pumping will be better for fish salvage and more than 2 and 3 which do not involve louver lifting and subsequent loss of bottomfish; 4)* have slightly lower water supply risk than 5, although reduced pumping is already part of this alternative. The reduction is a concession that will please resource agencies to the point that further reductions should not be requested, and higher than alternatives 8-10 because they entail creative harvesting; 5) quite possibly not be implementable this year because of contract complexity; 6) have an even lower PR rating than alternative 5 because of the reduction in pumping, and basically be the same as the lifting louvers only alternative because gains made in removing crabs are cancelled out by fish losses and reductions in pumping ; 7) have a crab elimination efficiency higher than alternatives 4 and 5 because of reduced pumping bringing in fewer crabs, but lower than TWS alternatives 2 and 3; 8) require NEPA, contracts, and rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish; and 9) probably not obtain stakeholder buyoff from water users because of reduced pumping, or the environmental community or resource agencies because of fish lost under louvers.

****Authority would not accept htis alternative as it requires a reduction in pumping (Appendix F).***

Alternative 6. Lift Louvers to allow crabs to pass through and Travelling Water Screen.

Alternative 6 was developed to combine the two very effective methods of eliminating crabs from salvage operations. Unfortunately, they are mutually exclusive. There is little value in doing one when doing the other. If the majority of the crabs are leaving the TFCF under the louvers, then a TWS would not be necessary. If the TWS works well, there is no reason to take the risks associated with lifting the louvers.

Alternative 6 would: 1)* be less costly than the alternatives which include intake crab removal (5,5a,7,7a), but more costly than Alternatives 2-4 which do not; 2) require 1-2 additional people to assist in operating the TWS; 3) have a lower fish salvage risk than alternatives 4 and 5 which do not include the TWS, the same as alternative 7, slightly higher than alternative 5a which includes reduced pumping, and significantly higher than alternatives 2 and 3 which do not require lifting of louvers; 4) has a slightly lower water supply risk than alternative 1 which has great uncertainty, higher than all but alternative 4 because they either include the TWS or intake channel crab removal or alternatives 8-13 because they entail creative harvesting, and the same moderately high level as alternative 4 because neither includes intake crab removal; 5) is implementable in time for the crab migration in 1999; 6) has a mid-range PR value, higher than those with reduced pumping (3,5a,7a) or lifting louvers only (4) and lower than those which mainly entail crab trapping or the TWS (2,5,7,8-13); 7) have a crab elimination efficiency less than those which employ even more methods of control (7-13) and those which only include the TWS (2) and greater than the No Action alternative and those without the TWS; 8) require NEPA, contracts, and rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring report on the TWS; and 9) not be expected to obtain stakeholder buyoff from the environmental community or resource agencies because of fish lost beneath the louvers.

Authority believes this method is not cost effective as it is redundant (TWS and lifting louvers doing the same thing)(Appendix F).

Alternative 7. Lift Louvers to allow crabs to pass through, Travelling Water Screen, and Remove crabs from the intake channel before they reach TPP (Tracy Pumping Plant) and points downstream in the DMC.

Alternative 7 was developed by combining the two very effective methods of eliminating crabs from salvage operations. Unfortunately, they are once again mutually exclusive. There is little value in doing one when doing the other; if the majority of the crabs are leaving the TFCF under the louvers, then the TWS would not be necessary. If the TWS works well, there is no reason to take the risks associated with lifting the louvers.

Alternative 7 would: 1) be moderate to high cost due to the cost of the contract to remove crabs from the DMC and mitigate lost fish but less than alternatives 5a and 7a which are similar but also require reduced pumping; 2) require 1-2 additional people (or more) to assist in operating the TWS and oversee the crab removal contract, which is more than any other alternative except the No Action alternative and #8 which require at least 2 people for assistance; 3) have a lower fish salvage risk than alternatives 4 and 5 which do not include the TWS, the same as #6, slightly higher than # 5a which has reduced pumping, and much higher than #2 and #3 which do not require lifting of louvers; 4)* has a much lower water supply risk than #1 which has great uncertainty, and #4 and #6 which do not include trapping, higher than #2 and #3 because they include a TWS and 8-13 because they entail creative harvesting, and similar to 5,5a, and 7a because they too include trapping; 5) quite possibly not be implementable in time for the crab migration in 1999 due to the complexity of contracts, etc.; 6) have moderate PR value, higher than those with reduced pumping (3,5a,7a) or lifting of louvers (4,5,5a,6,7), because it employs the TWS, but is less than #3 with TWS only and #s 8-13 because they avoid lifting the louvers and involve active removal of crabs; 7) have a crab elimination efficiency less than those which employ even more methods of control (#s 7,7a) and those which only include the TWS (#s 2 and 3) and greater than the No Action alternative and those without the TWS; 8) require NEPA, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; and 9) not be expected to obtain stakeholder buyoff from the environmental community or resource agencies because of fish lost under the louvers.

Authority believes this alternative would require more testing and trial methods to ensure that crabs are removed prior to the intake of the pumps, but may be an option for next year. Otherwise, there is too much risk to the water districts if crabs are pumped into the DMC (Appendix F).

Alternative 7a. Lift Louvers to allow crabs to pass through, Travelling Water Screen, Remove crabs from the intake channel before they reach TPP (Tracy Pumping Plant) and points downstream in the DMC, and Reductions in Pumping.

Alternative 7a was developed to combine several very effective methods of eliminating crabs from salvage operations. Unfortunately, they also may be mutually exclusive. There is little value in doing one when doing the other; if the majority of the crabs are leaving the TFCF under the louvers, then the TWS would not be necessary. If the TWS works well, there is no reason to take the risks associated with lifting the louvers. If the TWS does not work well because of overloading, then reduced pumping might be necessary.

Alternative 7a would: 1) be high cost due to the cost of additional manpower for the TWS and the contract to remove crabs from the DMC, the cost of the contract to mitigate lost fish, and cost to make up pumping; 2) require 1-2 additional people to assist in operating the TWS and oversee the crab removal contract, which is more than any other alternative except the No Action alternative and alternative 8 which require at least 2 people for assistance; 3) have a lower fish salvage risk than alternatives 4 and 5 which do not include the TWS, and the risky No Action, slightly less than those which are similar but do not reduce pumping, the same as 5a which does not have the TWS or reduced pumping, higher than those with the TWS (2 and 3) or creative harvesting (8-13) slightly higher than 5a which has reduced pumping and much higher than 2 and 3 which do not require lifting of louvers; 4)* has a much lower water supply risk than 1 which has great uncertainty, and 4 and 6 which do not include trapping, higher than 2 and 3 because they include the TWS and 8-13 because they entail creative harvesting, and similar to 5,5a, and 7 because they too include trapping; 5) quite possibly not be implementable in time for the crab migration in 1999 due to the complexity of contracts, etc.; 6) have a PR value as low as or lower than all but the No Action alternative because of reduced pumping and lifting of louvers; 7) have a high crab elimination efficiency because many methods of control have been confined with reduced pumping, less than the TWS alternative with reduced pumping (3) and trashrack alteration (9); 8) require NEPA, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; and 9) not be expected to obtain stakeholder buyoff from the environmental community or resource agencies because of fish lost under louvers, or the water user community due to reductions in pumping.

Authority believes this alternative would require more testing and trial methods to ensure that crabs are removed prior to the intake of the pumps, but may be an option for next year. Otherwise, there is too much risk to the water districts if crabs are pumped into the DMC (Appendix F).

Alternative 8. Harvest Crabs from in Front of TFCF, by Reclamation

The best place to remove crabs would be in front of the trashrack structure. Harvesting behind the trashrack structure would also be highly beneficial, but the lack of room to operate would be an issue, plus crabs would still pile up onto the trashrack stucture itself. If the crabs could be collected in front of the TFCF it would prevent crabs from entering the TFCF and allow for efficient fish salvage operations. There are advantages to Reclamation performing the work: knowledge of the facility, liability is already established, and the work would be better coordinated with along with the normal workload. Unfortunately, Reclamation may not have the time or resources to develop a method for harvesting the crabs in front of the TFCF.

Alternative 8 would: 1) be medium to high cost, assuming that the project would be expensive but that Reclamation could implement the alternative for less cost than a contract; 2) require at least 2 additional people, likely even more, to carry out the work. More than any other alternative; 3) have lower fish salvage risk than all but the TWS (2 and 3) and re-operation (10) alternatives; 4) have lower water supply risk than all but TWS only (2), harvesting in front of TFCF by contract (8a), and nonstructural barriers (9); 5)** quite possibly not be implementable in time for the crab migration in 1999 due to the complexity of designing a method for haresting crabs and getting it installed and operational; 6) have higher PR value than all except alternatives 8a and 13 which likewise remove crabs before they can impact the TFCF, and slightly higher than nonstructural barriers (9) which divert crabs from the TFCF but do not remove them from the Delta; 7) have a unknown crab elimination efficiency because removal methods have not been determined as of yet; 8) require NEPA documents in order to operate in front of the TFCF, which would likely be a negative declaration; 9) *be expected to obtain buyoff from all stakeholders.

NMFS withholds full acceptance of this alternative, depending on techniques.

*****Authority believes this would be an acceptable option if they had enough time to determine***

the method of removal and time to test its effectiveness (Appendix F).

Alternative 8a. Harvest crabs from in front of TFCF, by contract

This alternative was developed under the assumption that Reclamation would neither have the interest nor the resources available necessary to design, plan, and implement a crab harvest program for in front of the TFCF. Doing so under contract will require contract development and occasional coordination with TFCF operations staff. Actual methods have not even been determined, making the possibility of this happening this year a major uncertainty.

Alternative 8a would: 1) be high cost, assuming that the effort by contract would be more expensive than if done by Reclamation; 2) require fewer than one additional person to assist in overseeing the work; 3) have lower fish salvage risk than all but the TWS (2 and 3) and re-operation (10) alternatives; 4) have lower water supply risk than all but TWS only (2), harvesting in front of TFCF by Reclamation (8), and nonstructural barriers (9); 5)** not be implementable this year, require NEPA documents, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; 6) higher PR value than all except alternatives 8 and 13 which likewise remove crabs before they can impact the TFCF, and slightly higher than the nonstructural barriers (9) alternative which diverts crabs from the TFCF but do not remove them from the Delta; 7) have an unknown crab elimination efficiency because removal methods have not been determined as of yet; 8) require NEPA documents in order to operate in front of the TFCF, which would likely be a negative declaration, and require a somewhat complicated contract; 9) *be expected to obtain buyoff from all stakeholders.

***NMFS withholds full acceptance of this alternative, depending on techniques.*

*****Authority believes this would be an acceptable option if they had enough time to determine the method of removal and time to test its effectiveness (Appendix F).***

Alternative 9. Nonstructural barriers

Biological controls, including crabicides, sound, light deterents, electricity, sterilization, etc. are outside of the scope of the Tracy Office's research capabilities for the upcoming crab migration season. However, these alternatives were discussed as reasonable and prudent alternatives because one of them might prove to be quite effective in the future. None have been tried at the TFCF and each would probably require more time than is available to be set up. In the meantime, electricity, and, possibly, strobe lights, will be tested in the near future on crabs in the experimental fish screen in Denver at the TSC lab. There are too many questions at this time to be able to compare to the other alternatives.

***NMFS would like to see details of what we propose in order to comment.**

*****This alternative is acceptable to Authority, but with insufficient time to prove efficiency***

(Appendix F).

Alternative 10. Re-operation

The 1998 TFCF fish salvage operational modifications were crudely effective and marginally acceptable by DFG. This re-operation alternative was included in our discussions in order to explore further changes to last year's operations in the unlikely event that we will need to resort to last year's operations scenario. The major component of this particular alternative is to operate the TFCF during the day only, as most crabs are entrained at night, and assumes that those crabs that would have been entrained at night will not be entrained at all. This assumption may very well be flawed as it is not known for sure whether those crabs not being entrained at night won't simply be entrained during the next day's operations. This may well be the case as crabs were still entrained in experiments when TFCF pumps were turned on for several minutes at a time, weeks after pumping had ceased. This alternative carries an high degree of uncertainty. There is also valid concern over the loss of export water, unless it can compensated for. ***Other methods could include increased frequency of haulouts with fewer crabs and fish, increased manpower and labor-intensive manual crab removal throughout the TFCF, increasing the lift height of the lift screen in the holding tanks, and increasing the diameter both of the outlet pipe on the fish haul truck outlets on loadout buckets (as per DFGcomments, Appendix D). Such changes would salvage more fish but allow for easier transport of crabs, as well.***

Alternative 10 would: 1) incur potentially high costs to make up lost water; 2) require no additional manpower; 3) incur low fish salvage risk (assuming it works in theory); 4)* high water supply risk; 5) be implementable in time for the crab migration; 6) have moderate PR value as reductions in pumping would make it unpopular with water users but somewhat popular with the environmental community and resource agencies; 7) possibly not eliminate crabs, but simply delay them, yielding a low crab elimination efficiency; 8) not require environmental documentation as reduced pumping is already considered to be part of standard operating procedures under the existing 1992/1998 Agreement for TFCF operations; 9) not expected to obtain buyoff from water users.

Authority finds this alternaitve unacceptable in that there is no opprtunity to make up the lost pumping conveyance, too much risk to pumping losses (Appendix F).

Alternative 11. Harvest crabs from within TFCF (by contract)

This alternative was developed to explore the possibility of removing crabs from within the TFCF compound. There may be some advantages to doing this: 1) much of the necessary equipment could stay on-site, near operators who could monitor crab removal effectiveness; 2) contractors could remove all crabs, including those found in fish salvage and fish counts, taking them off Reclamation's hands; 3) save Reclamation the effort and time that they would expend themselves, in harvesting crabs. Major disadvantages include: 1) Fish Facility operators' time will likely be needed to assist when procedures do not go well; 2) space constraints at the TFCF may preclude the presence of an operation of the size needed to capture and process crabs; 3) untested interference with "criteria" flows required to efficiently salvage fish brought on by structures placed within the TFCF.

This alternative would: 1) be low direct cost to Reclamation, but high cost for a contract: overall moderate; 2) require less than one additional person; 3) have moderate to high fish salvage risk as effects of the harvest would be unknown until the work begins, and because there is a chance it could interfere with standard operating procedures; 4) have moderate to high water supply risk related to the uncertainty of the work's impacts on criteria flows, which, if appreciable, might prompt resource agencies to request a halt in pumping; 5)**quite possibly not be implementable in time for the crab migration in 1999 due to the complexity of contracts and designing effective crab harvest procedures; 6) have moderate PR value, but resource agencies might not support untested harvest methods; 7) effectively remove the crabs from the facility; 8) require NEPA documents, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; 9)*not be expected to obtain stakeholder buyoff due to the uncertainty of the entire operation.

NMFS withholds full acceptance of this alternative, depending on techniques.

*****Authority finds this alternative unacceptable in that there does not appear to them to be enough time to define an acceptable method of harbesting crabs without possibly interfering with the fish salvage (Appendix F).***

Alternative 12. TrashRack Alteration

Because most crabs can penetrate the trashrack structure, but not the louvers ***(shell dimensions do not allow it, sievenet observations behind the secondaries bear this out)***, it would be possible to prevent most crabs from entering the TFCF if the trashrack spacing was narrowed to the same size, or smaller, than that of the louvers. Reclamation would hire a contractor to build and install a new trash rack. Although this would likely prevent crabs from entering the TFCF, the rack would continuously foul up with debris and crabs, thereby not filtering fish the way it was originally designed. There would also be increased risk of differential head forming between the front and back of the trashrack, thus lowering the downstream water elevation and potentially overloading the structure. This alternative does not appear favorable as water agencies would not support a new structure that violates the salvage Agreement nor would water users support an alternative which would threaten their exports if it doesn't work.

Alternative 12 would: 1) be high cost to build the structure and possible shutdown of pumping if/when it does not work; 2) at least one additional person, maybe even two, would be needed to continuously clean the rack; 3) high fish salvage risk; 4)*high water supply risk; 5) not be implementable in time for the crab migration in 1999; 6) have potential for high PR value if the rack can be kept clean and agreement could be reached on altering the design of the facility; 7) have a very high crab elimination efficiency; 8) require NEPA, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; 9)* not be expected to gain stakeholder buyoff as water users will be concerned that the trashrack will not be able to hold up to the onslaught of debris and crabs and could threaten water exports.

**** Authority believes that there are no data to support the trash rack's ability to handle increased loads and that its loss could be catastrophic to the operation of the TPP and DMC (Appendix F).***

*****NMFS cautiously thinks this alternative might work with modern, automated design (Appendix E).***

Alternative 13. Collect crabs at barriers

This alternative would require that south Delta barriers be left in place through the end of October and entails collection of crabs at barrier culverts by personnel from other resource agencies. ***This alternative has since become quite unlikely as the water year began wet and barriers were not placed.***

This alternative would: 1) be low cost to Reclamation, as other agencies would be responsible ***for cooperating;*** 2) require no additional manpower (within Reclamation); 3) have the potential for low fish salvage risk and; 4) water supply risk; 5) quite possibly be implementable this year (1999); 6) have maximum PR value as crabs would be dealt with by an interagency effort and removed before they reach the TFCF & TPP; 7) have high crab elimination efficiency because should remove most of the crabs prior to reaching the TFCF; 8) require NEPA documents, contracts, rewriting of the existing 1992/1998 Agreement for TFCF operations because of operational changes and mitigation for lost fish, and effectiveness monitoring; and ***9) may or may not be expected to receive full support from all stakeholders as it represents an interagency approach to dealing with the mitten crab problem. The complication here is the potential for effects of barrier removal upon the possibly "soon to be listed Stanislaus/San Joaquin fall-run chinook salmon adult immigration. It may also affect delta smelt if their center of concentration is in this part of the Delta in specific water year types" (DFG comments, Appendix D). NMFS believes this may be a good idea, and less expensive than trying to do the same thing at the TFCF.***

The Authority would make this alternative their first choice s it removes the crabs farthest from the pumping plant, and would combine this alternative with #2.

Recommendations

This Year (1999), an Adaptive Management Process

The flow chart below details the decision process that the Tracy Office of the Bureau of Reclamation will follow. For the upcoming mitten crab migration, the Tracy Office recommends pursuing construction and installation of a travelling water screen (TWS) device and installing it in the secondary channel of the fish facility as an effective means of separating crabs from the fish and with minimal impact to fish salvage operations. Additional manpower will be on-duty to assist with operation of the TWS and on-call in the event that problems arise related to use of the TWS. Removal of the crabs from the facility will be pursued through contract. If for some reason a contract can't be set up, Reclamation will consult with DFG regarding alternative removal efforts.

In the event that the TWS alternative by itself does not work effectively, then immediate coordination and consultation will take place with the other resource agencies, stakeholders, and within Reclamation to determine alternative courses of action ***(contingency plans). If, for instance, the TWS is found to exert unacceptable impacts upon the fish (as determined by Tracy Office Management as well as by regulatory agencies), then we will pursue joint point of diversion with SWP. If this is not possible, we will have to either stop pumping or continue, facing the consequences. If the TWS exerts acceptable impacts upon the fish and works well, it will be the sole chosen method of crab control. If the impacts are acceptable, but the TWS is not keeping pace with an overabundance of crabs, then the option of also lifting louvers will be considered. If this is an option, then crabs will be removed from the DMC at the Byron Road siphon (Lloyd does not like this one). If this is not an option, we will consider joint point of diversion. If joint point is not an option, we will either stop pumping or continue, facing the consequences. In summary, there are at least five possible actions: 1) Sole TWS implementation; 2) joint point of diversion; 3) lift louvers and use TWS; 4) and cease pumping; or 5) continue pumping, with consequences (management will have to help me determine what we think the consequences will be). It may be possible that at any time any combination of these actions may be chosen as we feel appropriate.***

If no other alternatives are immediately available, the Tracy Office will resort to last year's operations modifications until directed otherwise ***(as discussed in paragraphs 2 and 3 on page 2 of this document).***

The Tracy Office also recommends that serious consideration be given towards collection of the crabs at the south Delta barrier sites. This has the potential for providing tremendous benefits to fish facility and pumping plant operations and if moved on could quite possibly be implemented this year.

May 20, 1999

Monitoring

The Tracy Office, through involvement with Denver TSC, and coordination with IEP, has been evaluating the TWS model in their Denver laboratory, through effectiveness (removal of crabs) and evaluative (impacts upon fish salvage) studies. Continuous effectiveness (as a crab removal method) and evaluation (of impacts upon salvage) monitoring will continue after the full sized unit is placed in the TFCF secondaries. Studies will also be undertaken using the fish friendly pumps to above ground holding tanks as a method of systematically separating crabs from fish. Any other new methods of crab control employed (impacts of louver lifting upon splittail, crab collection at siphon outlet, for example) will be subject to investigation, as well. These studies will be overseen by accredited fisheries scientists (professors) and follow a monitoring plan that is still in production.

Possible Mitigation

Mitigation requirements will be determined through evaluation of impacts upon salvage and loss, most noticeably to special status and endangered species. Mitigation will be partly a function of incidental take as calulated by regulatory agencies in response to results from research and monitoring efforts Reclamation undertakes in conjunction with crab management activities. Mitigation can be direct financial recompensation, or the stocking of salmon, striped bass, or sturgeon (will eat mitten crabs as well as replace fish lost to DMC),

habitat restoration, or other means.

Coordination

Recent developments pertaining to TFCF operations have indicated that the mitten crab management plan is, essentially, re-operation, and may be covered under other agreements which can be re-written to provide for more flexibility and interagency coooperation. One case in point is the 1992 Agreement between Reclamation and Fish and Game to Reduce and Offset Direct Fish Losses at the Tracy Fish Collection Facility, which is being re-written with consideration of anticipated operational changes, which could include mitten crab management. Another case in point is the SWP's mitten crab control plan, which is quite similar to ours. They intend to follow many of Reclamation's leads, as well as to diverge where they wish to act differently. Their alternatives for controlling crabs at their facility are likely to be more structural, and between their methods and Reclamation's, the best future means of crab control can be determined.

Future Years

Much of what will be implemented in future years depends on what does and what does not work this year. Between Reclalamtion and DWR, a full range of methods will be tested. For future years, the Tracy Office not only recommends continued thought be given towards collecting crabs at the south Delta barriers, but that other means of harvesting crabs throughout the Delta be seriously considered, especially in front of the TFCF. Alternative means of diverting crabs away from the confluence of the TFCF and TPP should also continue to be studied for viability.

Figure 1. Comparison between estimated numbers of Chinese mitten crabs entrained daily at the Tracy Fish Collection Facility in 10-minute fish counts in 1998 with trapping and 10-minute fish counts in 1997 and 1998no trapping

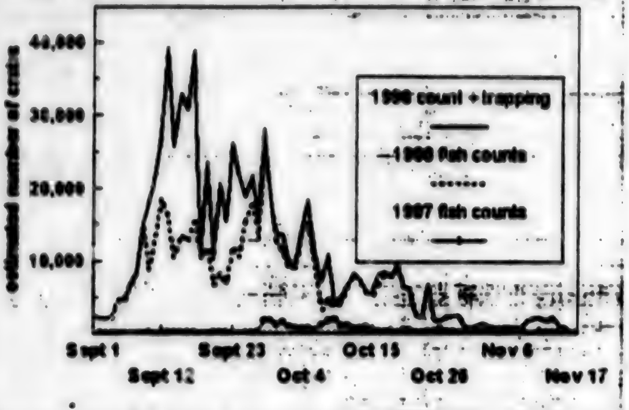


Figure 2. Comparison between estimated numbers of Chinese mitten crabs collected daily at the Tracy Fish Collection Facility (expanded) from 10-minute fish counts and daily low water temperature, 1997

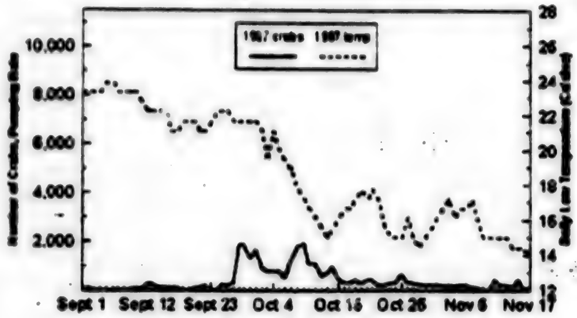


Figure 3. Comparison between estimated numbers of Chinese mitten crabs collected daily (with trapping) at the Tracy Fish Collection Facility, expanded from 10-minute fish counts and daily low water temperature

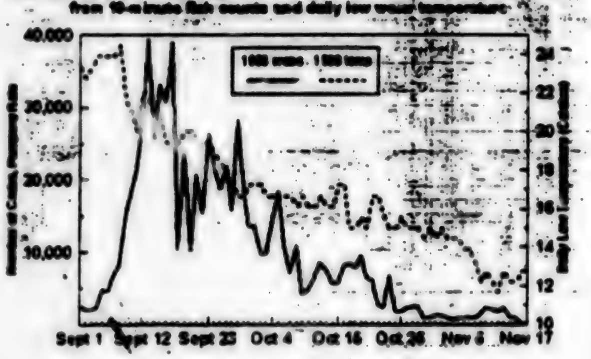
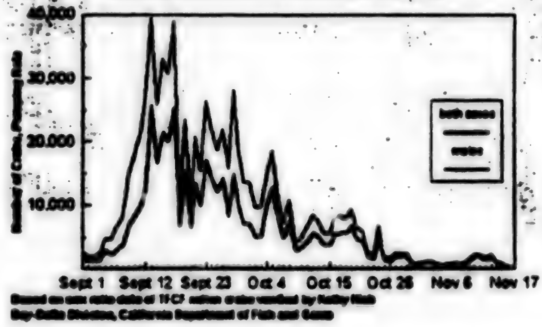


Figure 4. Sex ratio of Chinese mitten crabs collected daily at the Tracy Fish Collection Facility, expanded from 10-minute fish counts, September 1 - November 18, 1998



Based on sex ratio data of [illegible] mitten crabs verified by Kathy Hieb
Bay-Delta Division, California Department of Fish and Game

Figure 5. Diet composition of Chinese mitten crabs collected in 10-minute fish counts, with trapping, September 1 - November 18,1998

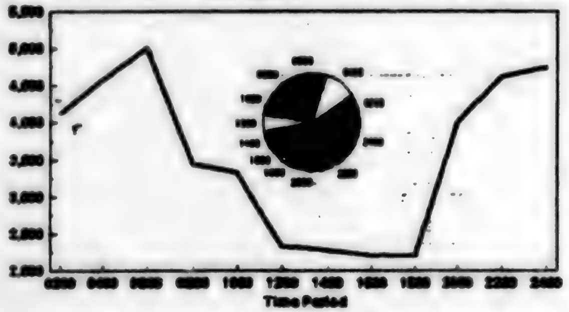
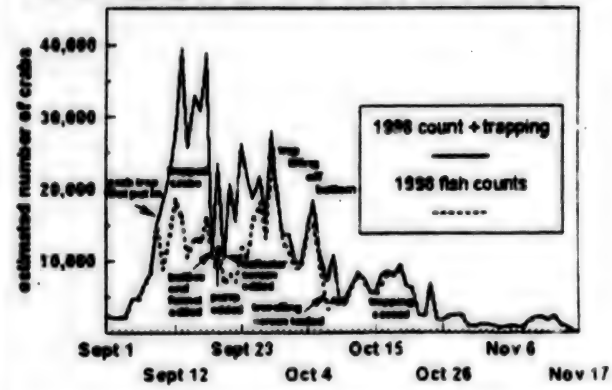


Figure 6. Comparison between estimated numbers of Chinese mitten crabs entrained daily at the Tracy Fish Collection Facility in 10-minute fish counts in 1998 with trapping, and 10-minute fish counts in 1998no trapping



Alternative	Cost	Additional Manpower	Fish Salvage Risk	Water Supply Risk	This Year?	PR	Crab Elimination Efficiency	Permits and Env Docs	Stake Holder Buyoff?
1. No Action	Lo/Hi	2	10	8	Y	1	1	No	No
2. Travelling Water Screen	Lo	1-2	3	2	Y	4	8	Report, Design. Agreement	Yes
3. Travelling Water Screen + reduced Pumping	Lo +H2O	1	2	*3	Y	2.5	9	Report, agreement	No
4. Lift Louvers	Lo +mit$	<1	7+	7+	Y	2	5-	NEPA	No
5. Lift Louvers +intake crab removal	M-Hi +mit$	<1	7+	3+	?	3	5+	NEPA, contracts	No
5a. Lift Louvers + intake crab removal + reduced pumping	M-Hi +mit$ +H2O	<1	6	3+	?	2	6+	NEPA, contracts, agreement	No
6. Lift Louvers +Travelling Water Screen	Lo +mit$	1-2	6+	7+	Y	2.5	6+	NEPA, report, agreement	No
7. Lift Louvers +Travelling Water Screen + intake crab removal	M-H +mit$	1-2+	6+	3+	?	3	7+	NEPA, contracts, agreement, report	Yes
7a. Lift Louvers + Travelling Water Screen + intake crab removal + reduced pumping	M-H +mit$ +H2O	1-2	6	3+	?	2	8+	NEPA, contracts, agreement, report	No
8. Harvest in front of TFCF by BOR	M-H	2+	3	2	N	4	5?	agreement	Yes
8a. Harvest in front (contract)	Lo	0	3	2	?	4	5?	contract	Yes
9.Nonstructural barriers	M-Hi	0	?	2	N	4	5?	report	Yes
10. Re-operation	Lo +H2O	0	2+	2+	Y	3-	3?	agreement, report	No
11. Harvest Crabs from within TFCF (contract)	Lo	<1	5+	5+	Y	3	5	agreement, report	Yes
12. Trash Rack Alteration	Hi	1+	8	8	N	3.5	9	agreement, report	No
13. Collect crabs at barriers	Lo	0	N/A	N/A	Y	4	8+	report	Yes

STATE WATER PROJECT PLAN FOR MITTEN CRAB EXCLUSION AND CONTROL AT THE SKINNER FISH FACILITY

JUNE 14, 1999

Over the past several months staff from Delta Field Division, Operations and Maintenance and Environmental Services Office met to develop a plan for controlling and excluding the Chinese Mitten crab from the Skinner Fish Facility.

OBJECTIVE

Exclude mitten crabs from the State Water Project and Skinner Fish Facility in numbers adequate to eliminate any curtailment of fish salvage or project export operations.

BACKGROUND

The Chinese mitten crab invades the State and Federal Water Projects pumping plants during its annual spawning migration in the months of September through November. In 1998, the spawning migration resulted in millions of crabs impacting fish salvage and project export operations at both the state and federal Delta facilities. At the Skinner Fish Facility crabs hindered fish salvage operations-and resulted in curtailed SWP pumping operations.

PROPOSED PLAN

Physical modifications

DWR proposes to install a mitten crab barrier upstream of the Skinner Fish Facility trash racks in the intake channel. The proposed barrier would be about a four foot high "k" rail-similar to a concrete highway barrier. It would be coated with a slick paint to minimize crabs attachment to it. It would be placed in sections at a diagonal across the intake channel (see Attachment). Since crabs move along the river bottom and do not swim in the water column, the barrier would divert crab movement away from the fish facility and along the upstream side of the barrier to a trap or collection point located on land or at the water edge. Delta Field Division would install the barrier by August 1, 1999. Captured crabs would be hauled off site for rendering as fertilizer or killed and buried on-site. Divers have inspected the intake channel and determined that it is suitable for placement of the barrier. Current restrictions on project export due to Delta smelt concerns have delayed efforts to measure intake channel velocity profiles. These measurements will take place prior to installation of the barrier once current restrictions are lifted.

DWR also proposes to install a screen at the Clifton Court radial gates. Each of the 5 radial gates would be fitted with a "Grizzly" metal screen 4 to 6 feet high with 1-inch openings. The screen would be constructed of vertical metal bars welded to a frame and fit into existing channels used to secure the stop logs. The gate screen will rest on the bottom substrate and provide a barrier to mitten crab movement but allow water passage when the radial gates are lifted.

DWR does not plan to install a travelling screen in the Skinner Fish Facility for crab removal. The proactive approaches proposed here focus on preventing mitten crabs from entering the Skinner Fish Facility. In addition, two travelling screens would be required at Skinner for each of the secondaries. Since USBR will be evaluating travelling screens at their Tracy facility, the DWR plan provides other options to control mitten crabs.

Operational Options

Operation of the Clifton Court Forebay Gates will be adjusted to reduce intake during hours of any potential peak crab migration periods identified in further research. This adjusted operation will occur within the requirements set forth in Standard Operating Order 200.7-A to protect south Delta water levels.

Shifting fish salvage operations between the primary and secondary holding tanks will allow one system to be cleaned of crabs while the other is in use. These shifts will be coordinated with operations scheduling to minimize disruptions to Banks Pumping Plant schedule.

Joint Point of Diversion between the export facilities will be pursued as a fishery protection measure and provide flexibility for operations in the event measures to control mitten crabs are inadequate. Staff are actively working with the USBR, SDWA and DWR Office of State Water Project Planning to develop a response plan in accordance with WR 98-9 to allow SWP operations to be shifted from Banks to Tracy Pumping Plant. The response plan will address south Delta water level concerns. In addition, coordination with fishery agencies will be pursued to identify the benefits to fishery salvage operations.

ACTION ITEMS

Delta Field Division will design and install the barrier in the intake channel. The 700 lineal feet of 'k'-rail has been delivered to the site. In addition, the field division will design, fabricate, and install the Clifton Court gate screens.

Operations and Maintenance will provide funding for barrier tests and will evaluate different flow and pumping conditions on the ability to trap crabs against the barrier when sufficient water is available to pump at Banks Pumping Plant.

JOC staff will coordinate with fishery agencies regarding operating guidelines and the potential for shifting operations between secondary channels to provide an opportunity for cleaning out mitten crabs without affecting export operations and endangered species take limits. JOC staff are also working on Joint Point of Diversion.

JOC staff will investigate forecasted tide and gate operations at CCF to determine if conditions will allow shifting of day/night intake operations. Staff will coordinate with operations scheduling and evaluate flexibility to operate intake gates during periods of low mitten crab activity.

ESO staff will also collect and evaluate data on temperature affects of mitten crab movement. This data will be used to determine if any potential benefits may result from adjusting CCF gate operations.

ESO and Department of Fish and Game staff will discuss procedures to improve counting and reporting of mitten crabs collected at the Skinner Fish facility.

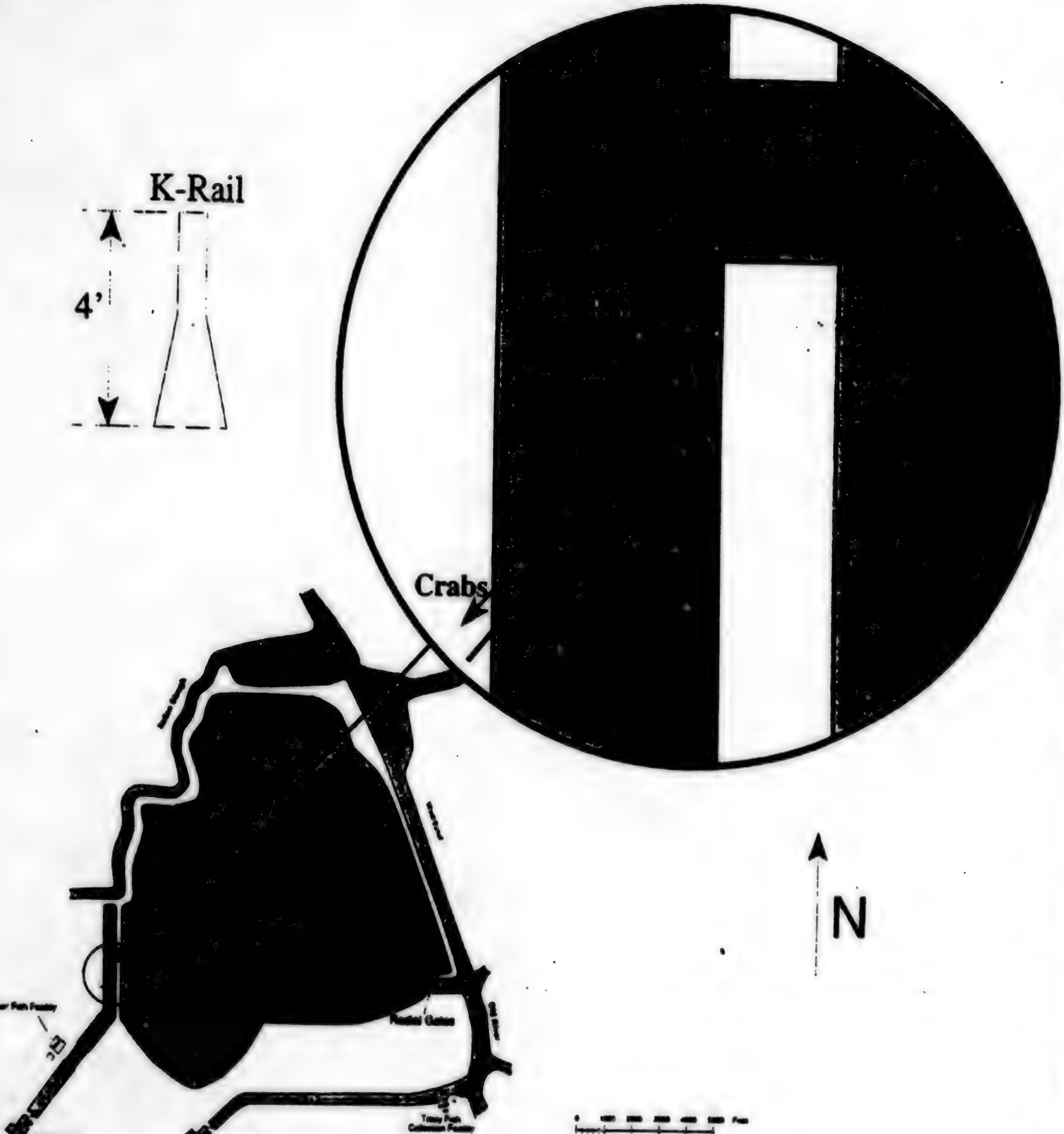
ESO and JOC staff will coordinate with Planning that the autumn Old River at Head barrier could have some benefits on reducing or delaying mitten crabs arrival at both state and federal facilities.

PARTICIPANTS

Delta Field Division—Joe Serpa and Jerry Raasch

Environmental Services Office—John Andrew and Ted Frink

Operations and Maintenance—Dan Peterson, Jeff Janik, and Victor Pacheco



South Delta Intake Facilities: Proposed mitten crab barrier.

STATE OF CALIFORNIA – THE RESOURCES AGENCY
GRAY DAVIS, *Governor*

DEPARTMENT OF WATER RESOURCES
ENVIRONMENTAL SERVICES OFFICE
3251 S STREET
SACRAMENTO, CA 95816-7017

June 28, 1999

✓ Ms. Kim Webb
U.S. Fish and Wildlife Service
3310 El Camino Avenue, Suite 130
Sacramento, California 95821

Mr. Gary Stern
National Marine Fisheries Service
777 Sonoma Avenue Suite 325
Santa Rosa, California 95404

Mr. Chuck Armor
California Department of Fish and Game
Interagency Ecological Program
4001 North Wilson Way
Stockton, California 95205-2486

Ms. Debra McKee
California Department of Fish and Game
Endangered Species
1701 Nimbus Road
Rancho Cordova, California 95670

Chinese Mitten Crab Experimental Exclusion Barrier "Grizzly" Bar Rack
Research Project, August - November 1999

The Department of Water Resources is planning to conduct a pilot study of a Chinese mitten crab exclusion grizzly bar rack at the radial intake gates at Clifton Court Forebay between August and November 1999. As the lead agency for CEQA compliance on the project, we concluded that there are no significant environmental impacts associated with the pilot study and that the project is categorically exempt under CEQA Guidelines Article 19, subsections No. 15301 and No. 15306. We filed a Notice of Exemption (NOE) on June 22, 1999, with the State Clearinghouse, Office of Planning and Research. For your information, I have enclosed a copy of the NOE with the project description as well as DWR's mitten crab control plan for 1999.

DWR has presented the project proposal to agency staff of the IEP Fish Facilities Mitten Crab Project Work Team and made a formal presentation on June 15, 1999, to the CALFED Ops Group. As part of the program implementation, I request your agency's review of the proposed plan and would like to receive comments or concurrence in writing as soon as possible, so that we may address or implement changes if necessary.

Notice of Exemption

To: Office of Planning and Research
1400 Tenth Street, Room 121
Sacramento, CA 95814

From: Department Of Water Resources
Environmental Services Office
3251 S Street
Sacramento, CA 95816

Project Title: Department Of Water Resources John Skinner South Delta Fish Salvage Facility Mitten Crab Exclusion And Control Experimental Guidance/Barrier Wall Research Project, August-November 1999

Project Location - County: Contra Costa **Project Location - City:** Byron, California

Project Location - Specific: 20 miles south-east of Stockton, adjacent to Old River on Italian Slough in the south Sacramento-San Joaquin Delta. T1S, R3E/R4E, Sections 24, 25, 12

Description of Project: DWR proposes to install an experimental guidance/barrier wall at the entrance of the intake channel in Clifton Court Forebay upstream of the primary fish screens at John E. Skinner Delta Fish Protective Facility. The experimental wall is designed to guide and collect Chinese mitten crabs before they are entrained into the fish salvage facility. The wall will be constructed of 10- and 20-foot by 4 foot high modular concrete highway barriers or K-rails placed end-to-end and angled across the entire intake channel. The crabs will be guided along the upstream side of the wall to the end of the barrier and into a collection device or trap. The angle of the wall will be about 30 degrees off the downstream flow. All collected crabs will be disposed of either on-site or by contracting with fertilizer or rendering companies for transport off-site. The wall is a temporary, stand-alone structure specifically for crab guidance that will augment the collection and handling facilities of the existing fish salvage facilities. This project is intended to reduce impacts on fish survival and salvage when large influxes of adult mitten crabs appear in September and October. Monitoring will be conducted to evaluate the effectiveness of the wall at diverting and collecting mitten crabs and reducing the number of crabs in the fish holding tanks during salvage. Ultimately, if the project results in better fish survival and salvage it may be implemented as a permanent feature of the fish protective facilities.

Name of Public Agency(ies) Approving Project: California Department of Water Resources, California Department of Fish and Game, National Marine Fisheries Service, US Bureau of Reclamation

Name of Person or Agency Carrying Out Project: California Department of Water Resources, California Department of Fish and Game

Exempt Status: 15301, 15306

Reasons Project is Exempt: The project is an experimental pilot project to determine the effectiveness of the guidance/barrier wall at excluding mitten crabs from the John E. Skinner Delta Fish Protective Facility and improving salvage and survival of fish collected at the facility. The project is a minor alteration to existing fish protection facilities to improve separation and handling of mitten crabs from fish and is expected to result in improved fish survival.

Lead Agency Contact Person and Phone: Ted Frink (916) 227-0177 or Dan Peterson (916) 653-9978

If Filed by Applicant:

1. Attach certified document of exemption finding.
2. Has a Notice of Exemption been filed by the public agency approving the project? ☐ Yes ☐ No

Signature: Dale K. Hoffman-Floerke for RLBrown **Date:** 6/10/99

Title: EPM I for EEA III

☑ Signed by Lead Agency
☑ Signed by Applicant

Date Received for Filing at OPR: ____________

RECEIVED
JUN 10 1999
STATE CLEARINGHOUSE

Appendix E

Current Status on the increasing abundance of the Chinese Mitten Crab *Eriocheir sinensis* in German rivers

Stephan Gollasch
1999

Current status on the increasing abundance of the Chinese Mitten Crab *Eriocheir sinensis* H. Milne Edwards, 1854 in German rivers

S. Gollasch
Institut für Meereskunde, Düsternbrooker Weg 20, 24105 Kiel, Germany

Introduction

The first European findings of the Chinese Mitten Crab were recorded from the German river Aller in 1912. Today specimens can be found up to 700 km upstream in German rivers (e.g. river Elbe) (Pax 1929, Peters et al. 1936). The maximum rate of spread of the crabs in German waters was concluded after tagging. Adult species migrating downstream can make 12 to 16 km daily (Peters et al 1936, Panning 1937 b). Via the Kiel Canal the species migrated into the Baltic Sea. First records in the Baltic Sea were made in 1926, but the centre of occurrence in Europe are still today the German rivers Elbe and Weser (Schnakenbeck 1924, Boettger 1933, Luther 1934, Kaestner 1970, Sukopp & Brande 1984, Anger 1990, Zibrowius 1991, Nyman 1993, Michaelis & Reise 1994, Gollasch 1997). It was generally agreed upon that shipping (ballast water and/or hull fouling of vessels) was the vector of introduction (Marquard 1926, Nepszy & Leach. 1973, Anger 1990, Jansson 1994, Gollasch 1997). In other areas imports of living species for aquaria or human consumption represent additional vectors (Marquard 1926, Peters 1933, Jazdzewski 1980, Howarth 1981, Carlton 1985).

The success of this invader was positively influenced by comparable conditions of climate and salinity in the area of origin (China) and recipient region (Europe). Additionally the lack of native decapods in estuarine waters and rivers of the North Sea area supported the establishment via low competition. The optimal abiotic conditions and low competition as well as immense food supply enabled a mass occurrence in German waters during 1930s-40s. Since than nearly every 15 years an increase of the population was observed with a new mass occurrence in the end of the 1990s. In 1938 Panning published his review on the Chinese Mitten Crab in German waters as a Smithsonian Report not knowing that the species will invade North American waters later in the end of the century.

Biology

The life-cycle of the predominantly night active Chinese Mitten Crabs is characterised by migrations in waters with changing salinities. The larvae are developing in marine waters. Their upstream migration (in spring) is supported by currents in estuaries. During high tides (upstream currents) the larvae are migrating into the water column and are transported by the currents. The developing young crabs and young adults are actively migrating in upstream direction. In their native distribution area living crabs were found 1400 km (!) upstream the river Jangtsekiang. The about four year old crabs migrate downstream backwards to the marine habitat in autumn. During their migration the organs for reproduction develop after they have reached brackish or salt water regions. In the marine environment the life-cycle completes after reproduction. The diet of the crabs includes a wide variety of algae, invertebrates, fishes and detritus. Their food consist up to half on algae and plants, but gastropods and bivalves are the predominate invertebrates consumed (Panning & Peters 1932, Panning 1937 b, 1952, Kaestner 1970, Anger 1990).

Abundance

In maximum more than 21 million juveniles were caught annually (about 240,000 kg) during their upstream migration in 1936 in the German rivers Elbe, Ems, Havel, Saale and Weser. The highest known daily catch was 2,500 kg (about 225,000 specimens) of juvenile crabs (Panning & Peters 1932, Panning 1950).

A research project was initiated in the mid of the 1990s focussing on the abundance of *E. sinensis* in German waters. In the beginning a questionnaire was mailed to more than 100 fishermen, waterway authorities and associated institutions asking for their knowledge on the abundance of the crab since the well documented period in the 1930s. As a result Fig. 1 was drawn indicating that there were five periods this century showing high densities of the crabs in the river Elbe (1930 – 1939, 1953 – 1960, 1969 – 1975, 1979 – 1983 and 1993 – present). The abundance of the crabs during the 1950s to 1980s were of minor importance compared to those of the 1930s (Fladung, pers. comm.) (Fig. 1 + 2). It is believed that the population decrease since the 1930s′ mass occurrence is correlated to increasing water pollution in German rivers (Anger 1990) and/or on abiotic factors, such as salinity and temperature constituting a positive impact on the survival rate of the larvae of the crab during special circumstances (Fladung pers. comm.). Furthermore, the size of the megalopa larvae after cold spring periods is about half compared to the population after warm spring periods. It is believed that smaller individuals have a higher mortality (Panning 1950) and therefore, that warm spring periods support high densities of larvae and juvenile crabs.

The increasing water pollution negatively effected the abundance of the prey of *E. sinensis*, the crab itself is able to tolerate heavily polluted waters. The lack of prey has an adverse impact on the crabs density by increasing the rate of naturally occurring cannibalism of the crabs. Recently the condition of the rivers became better (Reincke 1993) and the population density of *E. sinensis* is increasing. Beside the decreasing water pollution ("unlimited food suply") and the temperature during larval development, a third factor could be controlling the upstream migration activity of the juvenile crabs: the water load of the river. Strong water currents caused by high water loads may stimulate the migratory behaviour as shown in German waters (Fladung pers. comm.).

Since the beginning of the 1990s, about 60 years after the known extreme mass occurrence in German rivers, the Chinese Mitten Crab, *Eriocheir sinensis*, is now becoming very abundant again (Fig 1 + 3). In spring 1998, 850 kg of juvenile crabs (approx. 75,000 specimens) were caught by hand in the river Elbe in two hours only (!) (Strauch unpubl. data.). It is supposed that the daily catch could summarize to more than 3,000 kg of juvenile crabs (270,000 specimens). This amount of species is comparable to the data of the 1930s (in max. 2,500 kg of crabs were caught in one day), the peak of the former mass occurrence in German waters.

It is interesting to note that the populations of *E. sinensis* in the Thames river (Clark et al. 1998) and in Dutch waters (Wolff pers. comm.) are increasing as well.

Impacts

The crab is a competitor for food of benthic fishes (target species for human consumption, such as eel and flat fish) and preys upon native gastropods and bivalves, such as *Sphaerium* spp. (was locally driven extinct after the mass occurrence of the Chinese Mitten Crab in several localities of the river Elbe) and crustaceans, such as *Gammarus* sp. and *Crangon crangon* (Panning & Peters 1932, Peters et al. 1936).

The fishing industry in estuaries was threatened by the reduced catch of fish in fishing nets due to predation of the crabs on caught fish and bait as well as by destroyed fishing nets due to rope cutting of the crabs. Furthermore, the freshwater fisheries were threatened where the crab is known as a predator upon pond-fishes (preying on the fish and the fish food) (Panning & Peters 1932)

In addition to the loss of the harvest of the estuarine and inland fishing industry the crab is known to cause damages to dams, retaining walls and irrigation channels by performing them with burrows. The burrowing activities of the crabs were of special concern during the its mass occurrences. Openings of the burrows reach 12 cm in diameter and the burrows reach a length of 50 cm (Panning & Peters 1933, Peters et al. 1936). During the mid 1930s up to 30 holes per meter square in river banks of the mouth of river Elbe were found (Peters et al 1936).

In order to minimize the negative impacts different controlling mechanisms (e.g. selective fishing and traps) were installed with limited success (Panning & Peters 1932, Peters et al. 1936, Panning 1952, Leppäkoski 1991, Gruner et al. 1993). Options for the biocontrol, the intentional introduction of parasites or disease agents, were discussed, but not tested in the wild (Peters et al. 1936).

Another unwanted impact does, so far, only occur in its native range. The crab is known to be an intermediate host of the human oriental lung fluke disease. It is unlikely that this disease will establish in German waters due to the absence of the first intermediate gastropod host. This disease is a severe problem in certain Asian regions (Marquard 1926).

During its mass occurrence in German waters the crabs were collected and used as bait, food for cattle and chicken (in a crushed condition), main component of fish meal for cattle and "natural" aroma for fish soups. Cooked crabs were used as agricultural fertiliser in some places (Peters et al. 1936, Panning 1952). Furthermore, crabs were tested on the market for human consumption. Some people believed the meat is as tasty as from other crustaceans, but the market in Germany did not accept this new species (Panning & Peters 1932, Peters et al. 1936, Panning 1952). Knowing that many European rivers systems are contaminated with chemical substances, this option needs further consideration. Today, by-catches of any kind of crustaceans were used to extract substances, such as Chitosan, for cosmetic products.

Dutch and German fisherman are in close contact with Chinese institutions planning to export living juveniles from Europe to China for re-stocking the declining population of *E. sinensis* in China. One German fisherman holds the option to export 10 tonnes of juvenile crabs to China annually. Furthermore, neighbouring countries (Taiwan, Chorea and Japan) expressed their interest to import living specimens from Germany (Lasner & Schijven pers. comm.).

Knowing the unwanted impacts caused by Chinese Mitten Crabs in former times the estuarine and inland fishing industry expressed their concerns today. Due to the lack of data on the effectiveness of the installed crab traps it can not be excluded that the abundance of the crabs will increase further.

Literature cited

Anger, K. (1990): Der Lebenszyklus der Chinesischen Wollhandkrabbe (*Eriocheir sinensis*) in Norddeutschland: Gegenwärtiger Stand des Wissens und neue Untersuchungen. Seevögel, **11**, (2), 32-37 pp. [in German]

Boettger, C. R. (1933): Die Ausbreitung der Wollhandkrabbe in Europa. Sitzungber. Ges. naturforsch. Freunde, Berlin 1933., 399-415 pp. [in German]

Clark, P. F., Rainbow, P. S., Robbins, R. S., Smith, B., Yeomans, W. E., Thomas, M. & Dobson G. (1998): The Alien Chinese Mitten Crab, Eriocheir sinensis (Crustacea: Decapoda: Brachyura), in the Thames Catchment. J. mar. Biol. Ass. U.K., **78**, 1215-1221

Carlton, J. T. (1985): Transoceanic and interoceanic dispersal of coastal marine organisms: The biology of ballast water. Oceanogr. Mar. Biol. Ann. Rev., **23**, 313-371 pp.

Gollasch, S. (1997): Eriocheir sinensis. In: Baltic Research Network on Ecology of Marine Invasions and Introductions. S. Olenin and D. Daunys (eds.). World Wide Web http://www.ku.lt/nemo/mainnemo.htm, or: http://www.ku.lt/nemo/ericho.htm); 3 pp.

Gruner, H.-E.; Moritz, M. & Dunger, W. (1993): Wirbellose Tiere. In: Gruner, H.-E. (ed.), 4. Teil: Arthropoda (ohne Insecta). Bd. 1, Gustav Fischer, 4. Aufl., 1279 pp. [in German]

Howarth, R. S. (1981): The presence and implication of foreign organisms in ship ballast waters discharged into the Great Lakes. In: Casson, D. M.; Burt, A. J.; Joyner, A. J. & Heinermann, P. (eds.), (Bio-Environmental Services LTD.) The Water Pollution Control Directorate Environmental Protection Service Environment Canada, Georgetown, 97 pp.

Jansson, K. (1994): Unwanted Aquatic Organisms In Ballastwater. International Maritime Organization, MEPC, **36**, (INF.20), 1-68 pp.

Jazdzewski, K. (1980): Range extension of some Gammaridean species in European inland waters caused by human activity. Crustaceana, **6**, 84-107 pp.

Kaestner, A. (1970): III. Crustacea. Invertebrate Zoology. John Wiley and Sons Inc., New York, 523 pp. [in German]

Leppäkoski, E. J. (1991): Introduced species - Resource or threat in brackish-water seas? Examples from the Baltic and the Black Sea. Mar. Poll. Bull., **23**, 219-223 pp.

Luther, A. (1934): Über die ersten in Finnland gefundenen Exemplare der Wollhandkrabbe (*Eriocheir sinensis* MILNE-EDW.). Memo. Soc. Fauna Flora Fennica, **10**, 69-73 pp. [in German]

Marquard, O. (1926): Die Chinesische Wollhandkrabbe, *Eriocheir sinensis* MILNE-EDWARDS, ein neuer Bewohner deutscher Flüsse. Fischerei, **24**, 417-433 pp. [in German]

Michaelis, H. & Reise, K. (1994): Langfristige Veränderungen des Zoobenthos im Wattenmeer. In: Lozán, J. L.; Rachor, E.; Reise, K.; Westernhagen, H. v. & Lenz, W. (eds.), Warnsignale aus dem Wattenmeer. Bd. 2, Blackwell Wissenschafts-Verlag, Berlin, 106-116 pp. [in German]

Nepszy, S. J. & Leach, J. H. (1973): First Records of the Chinese Mitten Crab, *Eriocheir sinensis*, (Crustacea: Brachyura) from North America. J. Fish. Res. Bd. Canada, **30**, (12), 1909-1910 pp.

Nyman, M. (1993): Introducerade arter i Bottniska viken. Diss. Dept. Biol., Abo Akademi Univ., 42 pp. [in Swedish]

Panning, A. (1937 a): Die Verteilung der Wollhandkrabbe über das Flußgebiet der Elbe nach Jahrgängen. Mitt. Hamb. Zool. Mus. Inst. Hamb., **47**, 65-82 pp. [in German]

Panning, A. (1937 b): Über die Wanderung der Wollhandkrabbe. Mitt. Hamb. Zool. Mus. Inst., **47**, 32-49 pp. [in German]

Panning, A. (1938, a): The chinese Mitten Crab. Smithsonian Rep., 361-375 pp.

Panning, A. (1938, b): Systematisches über *Eriocheir sinensis* H. MILNE-EDWARDS. Mitt. Hamb. Zool. Mus. Inst. Hamb., **47**, 105-111 pp. [in German]

Panning, A. (1950): Der gegenwärtige Stand der Wollhandkrabben-frage. Neue Ergebn. und Probl. Zool., 719-732 pp. [in German]

Panning, A. (1952): Die chinesische Wollhandkrabbe. Die neue Brehm-Bücherei, (70), 1-46 pp. [in German]

Panning, A. & Peters, N. (1932): Wollhandkrabbe und Elbfischerei. Hamb. Nachr., (6), 1-16 pp. [in German]

Panning, A. & Peters, N. (1933): Die chinesische Wollhandkrabbe (*Eriocheir sinensis* MILNE-EDWARDS) in Deutschland. Zool. Anz., Vol. 101, 9/10, 265-271 [in German]

Pax, F. (1929): Auftreten der chinesischen Wolhandkrabbe (*Eriocheir sinensis* MILNE-EDWARDS) im Odergebiet. Zool. Garten, **1**, (7/9), 324-326 pp. [in German]

Peters, N. (1933): B. Lebenskundlicher Teil . In: Peters, N. & Panning, A. (eds.), Die chinesische Wollhandkrabbe (*Eriocheir sinensis* H. MILNE-EDWARDS) in Deutschland. Akademische Verlagsgesellschaft mbH, Leipzig, 59-156 pp. [in German]

Peters, N.; Panning, A.; Thiel, H.; Werner, H. & Schmalfuß, H. (1936): Die chinesische Wollhandkrabbe in Europa. Der Fischmarkt, (4/5), 1-19 pp. [in German]

Reincke, H. (1993): Belastungssituation der Elbe mit Nährstoffen. In: Nordseeküste, Schutzgemeinschaft deutsche (ed.), Eutrophierung und Landwirtschaft. Clausen & Bosse, Leck, 14-29 pp. [in German]

Schnakenbeck, W. (1924): Ueber das Auftreten chinesischer Krabben in der Unterelbe. Schr. für Süßwasser- und Meereskunde, (5), [in German]

Sukopp, H. & Brande, A. (1984): Beiträge zur Landschaftsgeschichte des Gebietes um den Tegeler See. Sitzungsber. Ges. Naturforsch. Freunde Berlin, **24**, 198-214/1-7 pp. [in German]

Zibrowius, H. (1991): Ongoing Modification of the Mediterranean Marine Fauna and Flora by the Establishment of Exotic Species. Bull. Mus. Hist. Nat. Marseille, **51**, 83-107 pp.

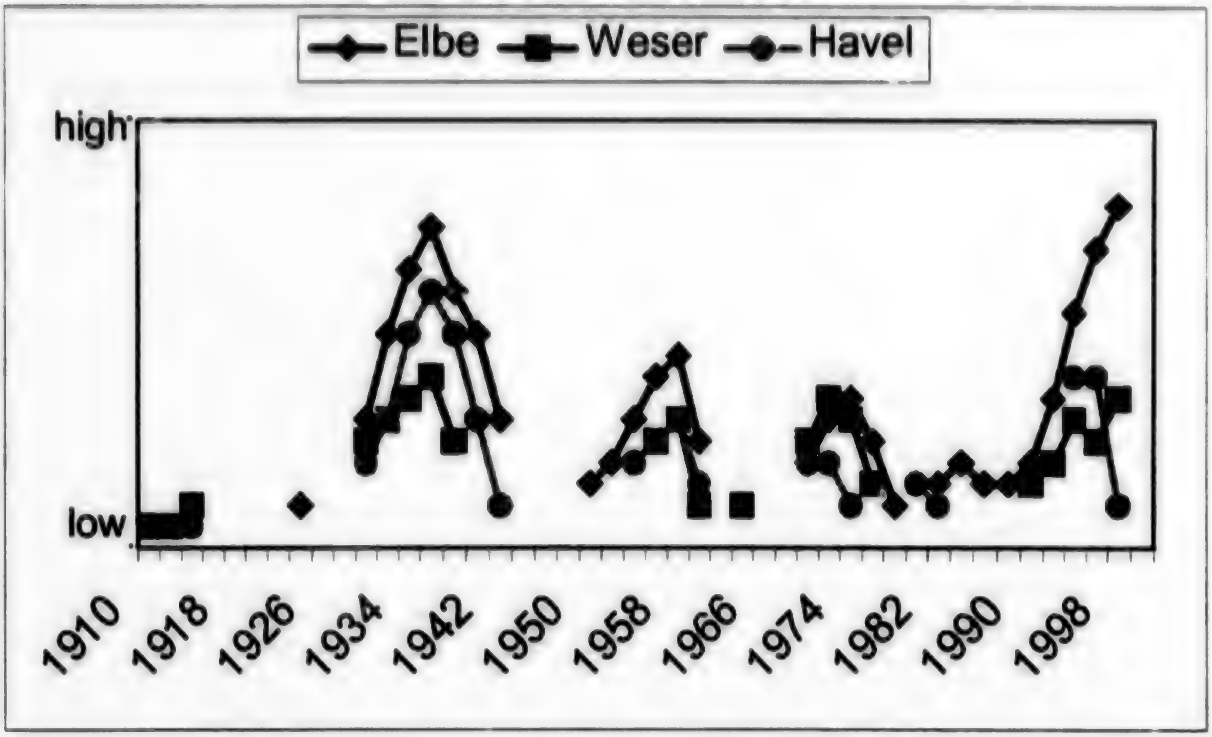


Fig. 1 Abundance of the Chinese Mitten Crab in German waters (rivers Elbe = black line, Weser = light grey line and Havel = dark grey line) since its introductions in 1908. The figure roughly indicates the crab density based on "semi-quantitative" information from fishermen, waterway authorities and associated institutions (Data source Fladung unpubl. data).

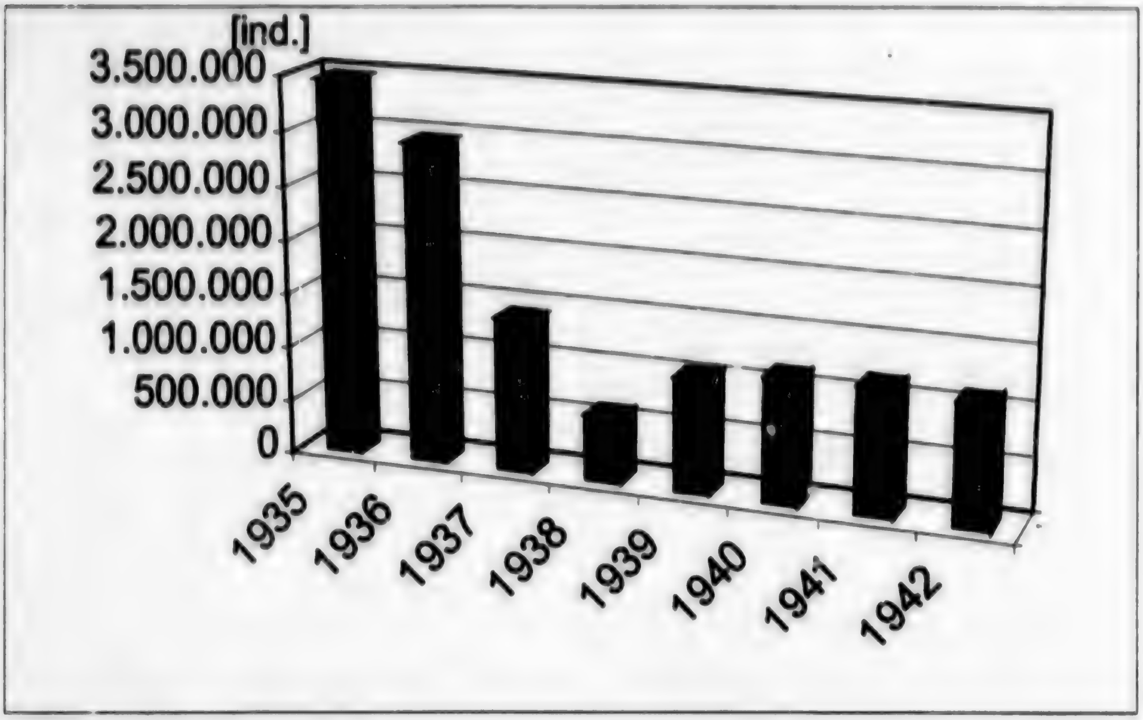


Fig. 2 Annual catch (individuals) of *Eriocheir sinensis* in the German river Weser, near Bremen (data source: Panning 1950).

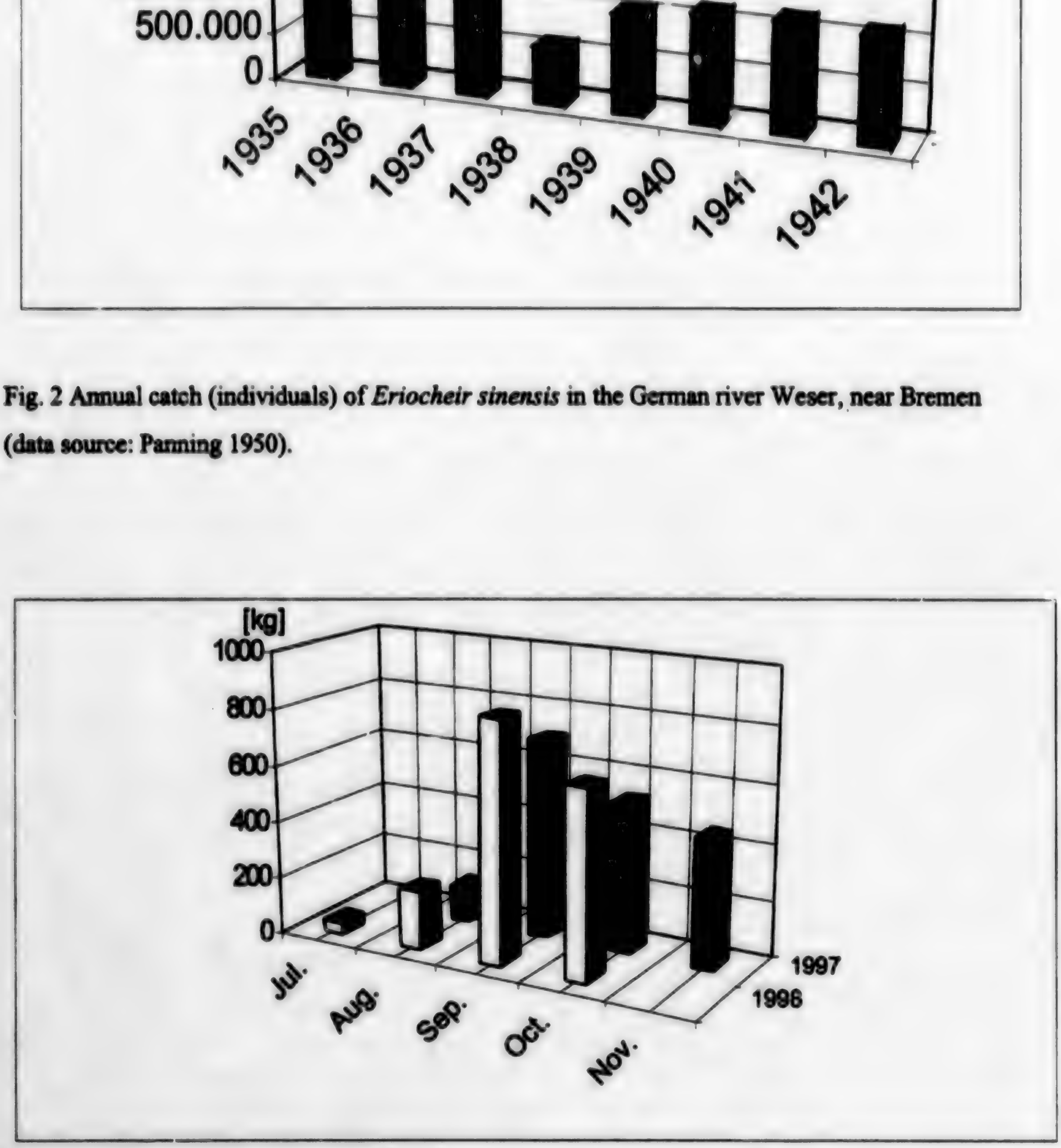


Fig. 3 Chinese Mitten Crab catches 1997 and 1998 in the Netherlands in kg reported by fisherman (Lasner & Schijven pers. comm.).

Appendix F

The Alien Chinese Mitten Crab, *Eriocheir sinensis* (Crustacea" Decapoda:Brachyura), in the Thames Catchment

Paul Clark, Philip Rainbow, Roni Robbins, Brian Smith, William Yeomans, Myles Thomas and Gina Dobson

1998

J. Mar. Biol. Ass. U.K. (1998), 78, 1215–1221
Printed in Great Britain

THE ALIEN CHINESE MITTEN CRAB, *ERIOCHEIR SINENSIS* (CRUSTACEA: DECAPODA: BRACHYURA), IN THE THAMES CATCHMENT

PAUL F. CLARK, PHILIP S. RAINBOW[*], RONI S. ROBBINS, BRIAN SMITH[*], WILLIAM E. YEOMANS[†], MYLES THOMAS[‡] AND GINA DOBSON

The Natural History Museum, Cromwell Road, London, SW7 5BD. [*]School of Biological Sciences, Queen Mary & Westfield College, University of London, London, E1 4NS. [†]Environment Agency, Biology Laboratory, Reading, RG2 0SF. [‡]Environment Agency, Apollo Court, 2 Bishops Square Business Park, St Albans Road West, Hatfield, Herts, AL10 9EX

Eriocheir sinensis, the Chinese mitten crab, is a native of east Asia and predominantly lives in freshwater but migrates seawards to breed. In 1912 a specimen was collected in the River Aller, a tributary of the Weser, Germany and now this exotic species has a European distribution from Finland to the Atlantic coast of southern France. In the UK, the mitten crab has been reported from the Humber, Medway and Thames catchments. Although the population in Thames had remained low, recent evidence suggests it is increasing, which has potential environmental implications.

INTRODUCTION

The Chinese mitten crab, *Eriocheir sinensis* H. Milne Edwards, 1854, originates from the Far East, with a native distribution from the Province of Fukien, China, ~26°N northwards to the Korean Peninsula ~40°N. Mitten crabs are catadromous, spending most of their life in freshwater, returning to the sea to breed. Males and females move downstream during late summer and attain sexual maturity in tidal estuaries. According to Panning (1939), the females are thought to continue seaward after mating, overwintering in deeper water before returning to brackish water in the spring to hatch their eggs. Larval development probably occurs in the lower estuary, with juvenile crabs gradually moving upstream into freshwater to complete the life cycle.

Eriocheir sinensis was introduced into Germany in 1912 (Panning, 1939) and has spread subsequently throughout northern Europe. Its present estimated distribution ranges from Finland (Haahtela, 1963), through Sweden, Russia, Poland, Germany, the Czech Republic (Prague), Netherlands, Belgium and England to France. The southernmost Atlantic coast record is the Golfe de Gascogne (Vigneux et al., 1993), France, but the crab has extended its range via the Garonne canal system to Sigean (Petit, 1960), Languedoc-Roussillon, southern France. The crab has also been reported from North America (Nepszy & Leach, 1973; Horwath, 1989; Cohen & Carlton, 1997).

It was first recorded from the British Isles by Harold (1935), when a specimen was captured on the intake screens of Lots Road Power Station, Chelsea. It has since been reported from the Thames, Medway and Humber catchments and from Southfields Reservoir, near Castleford in Yorkshire.

In the Thames catchment, the mitten crab population remained relatively constant through the 1970s and 1980s. Ingle & Andrews (1976) recorded three male crabs from the intake screens of the West Thurrock generating power station, located ~36 km downstream of the City of London. Three years later an ovigerous crab was collected at Southend-on-Sea and a further 20 specimens were noted by Andrews et al. (1982) again from West Thurrock. Additions to The Natural History Museum reference collection prior to 1996 included specimens from the Thames at Twickenham and Thames Ditton and from the grounds of West Middlesex Hospital near Syon Park. Since 1990 increasing numbers of mitten crabs have been collected from the intake screens from Lots Road power station, Chelsea. Figure 1 illustrates the known distribution records of mitten crabs in the Thames catchment up to November 1995.

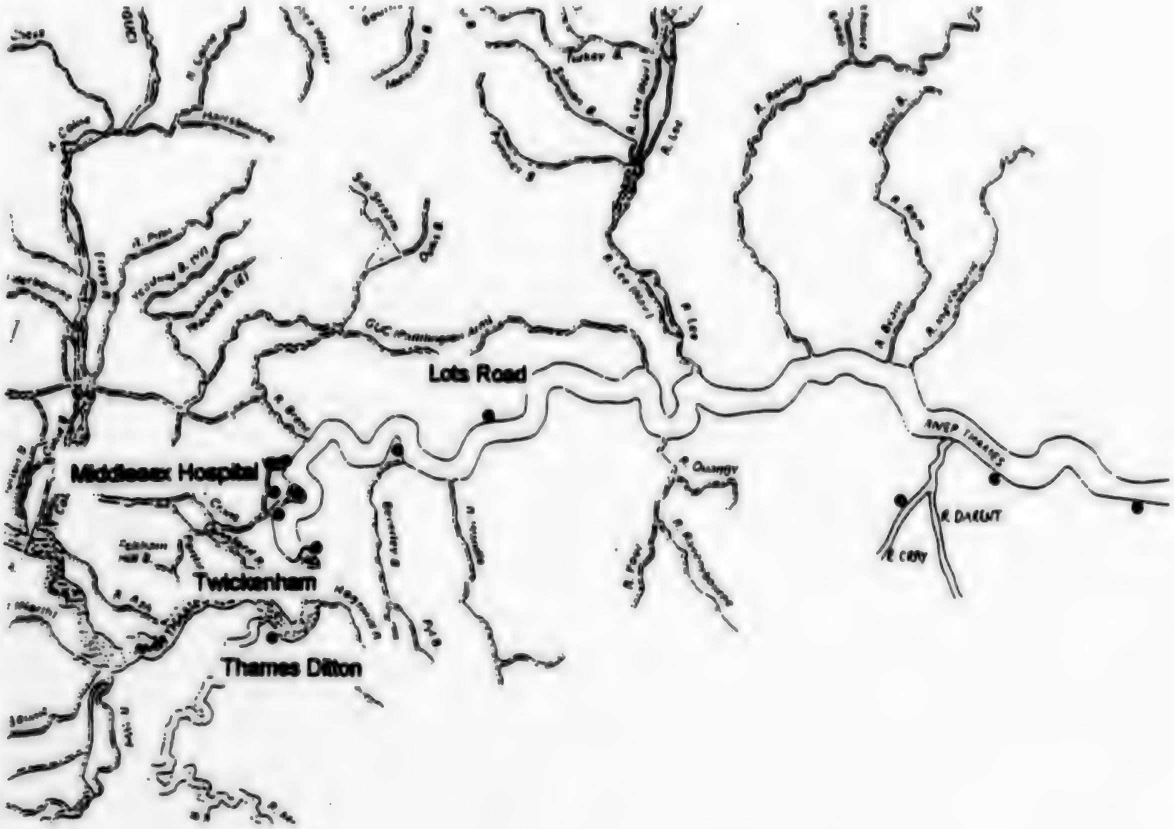


Figure 1. Distribution of *Eriocheir sinensis* in the Thames catchment from Natural History Museum specimens collected between May 1976 and November 1995.

RESULTS

In 1996 an appeal was made for mitten crab sightings and from 27 August to 15 November, 162 reports were received. Figure 2 shows the updated distribution in the Thames catchment. *Eriocheir sinensis* is now known from as far west as the River Colne

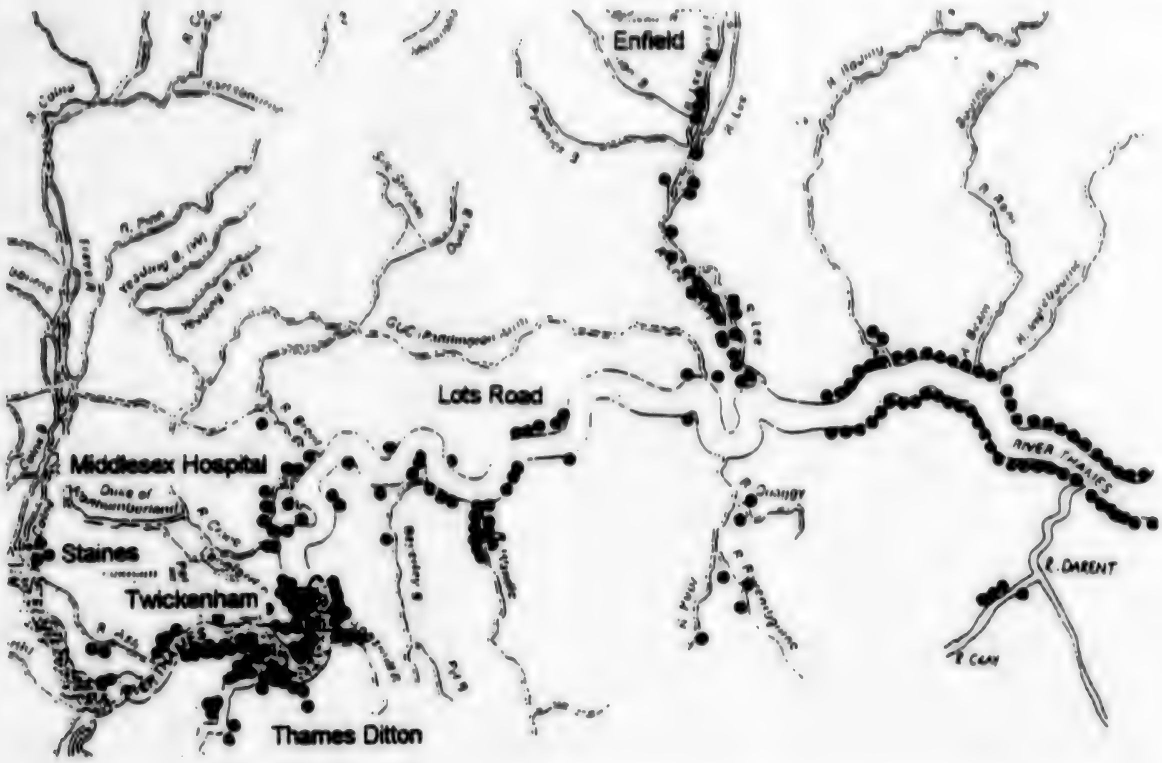


Figure 2. Distribution of *Eriocheir sinensis* in the Thames catchment from information received between 27 August 1996 and 15 November 1996.

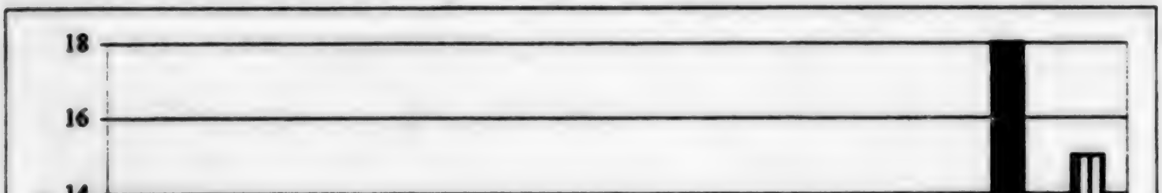


Figure 3. Numbers of *Eriocheir sinensis* collected at West Thurrock Power Station from 1976 to 31 March 1993 (incomplete data hatched) when electricity generating ceased.

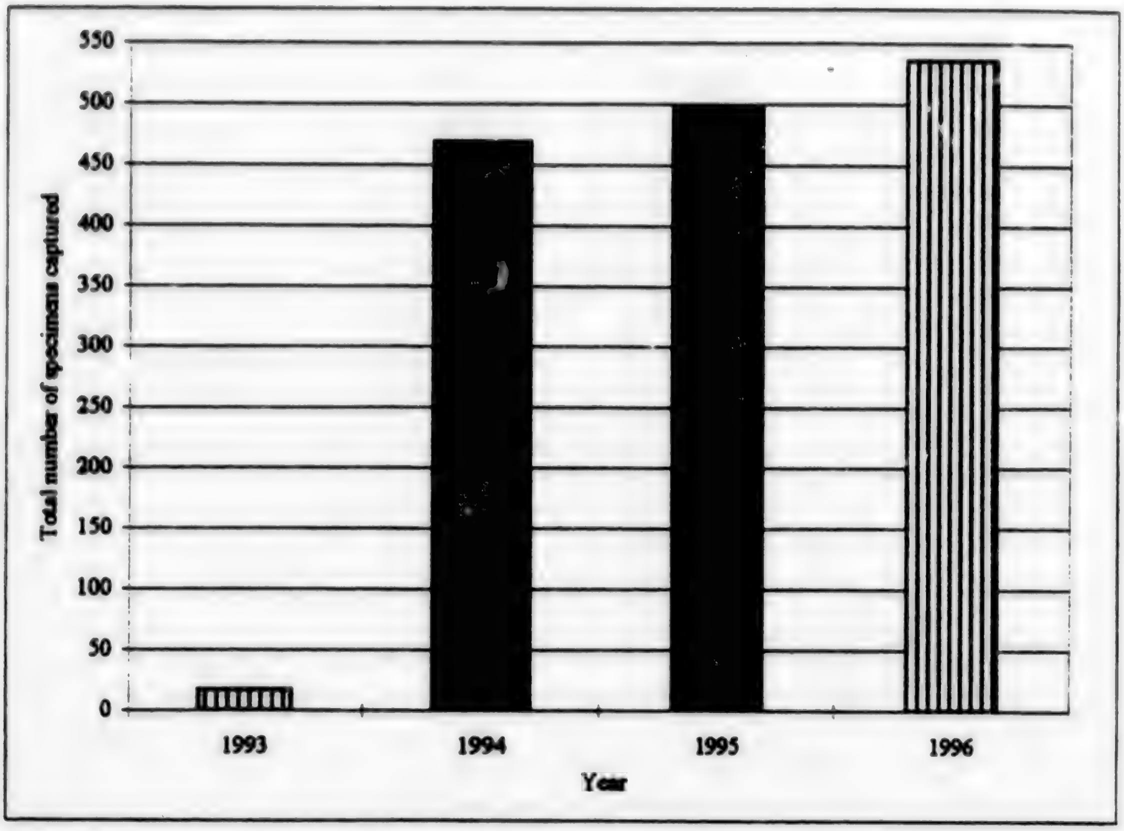


Figure 4. Numbers of *Eriocheir sinensis* collected annually at Tilbury Power Station from October 1993 (incomplete data hatched) to June 1996 (incomplete data hatched).

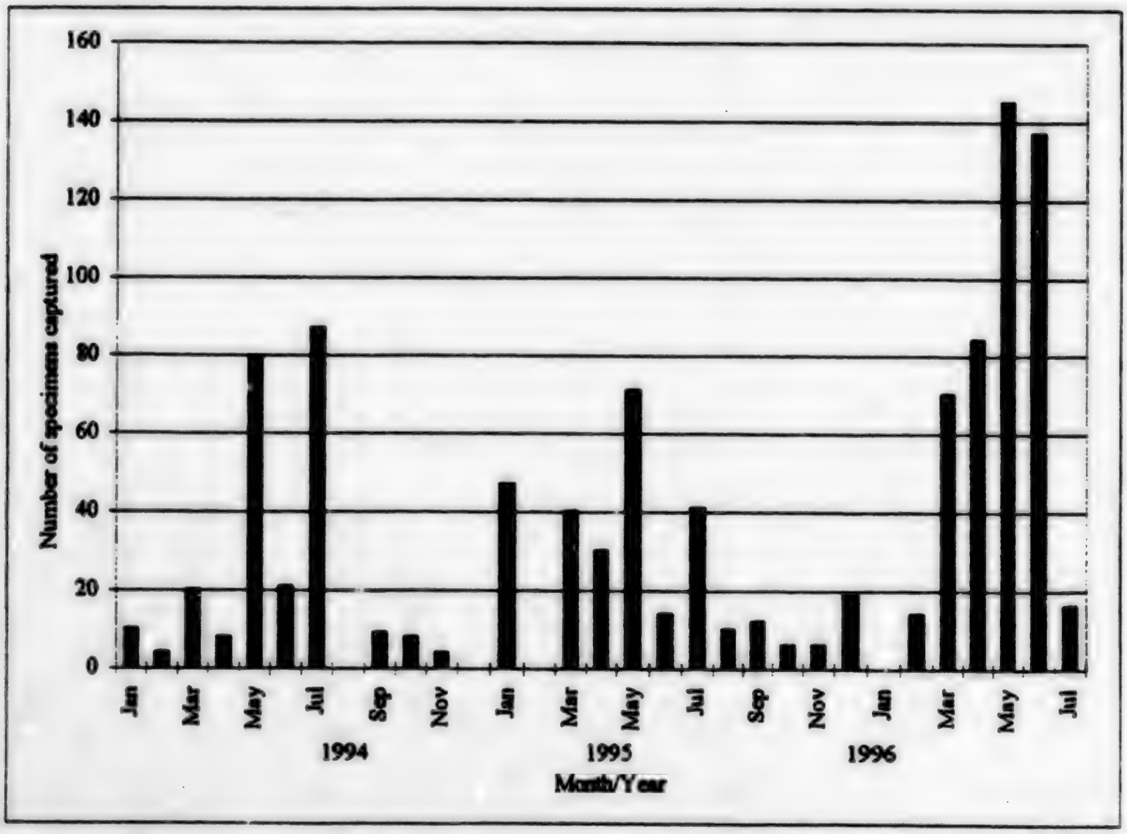


Figure 5. Monthly captures of *Eriocheir sinensis* from the intake screens at Tilbury Power Station (average number in four hour collections at two week intervals) from January 1994 to July 1996.

at Staines and is present in most of the Thames tributaries downstream of this point. In the east, the crab has been found in the Cray, Darent, (C. Dutton, personal communication) Quaggy, Pool and Ravensbourne. In the north-east, sightings are common in the rivers Roding and Lee. The most northerly report of *E. sinensis* is in the River Lee at Enfield, some 15 km upstream of the River Thames. The survey also recorded *E. sinensis* in every tributary from Chelsea upstream to Chertsey. The furthest upstream record at Staines is ~65 km from Tilbury.

The population of *Eriocheir sinensis* is now firmly established in the Thames catchment and, since 1992, has been increasing in numbers as well as geographical range. Environment Agency records include data on the total number of crabs collected from the filter screens at West Thurrock (1976–1993) and Tilbury (1993–1996) power stations. Small annual numbers of mitten crabs were collected at West Thurrock power station in the late 1970s and 1980s, but there was a population increase in 1992 that continued in 1993 until the power station closed in March (Figure 3). Large numbers of crabs were collected from Tilbury power station in 1994 and 1995 with at least as many in the first half of 1996 when collecting ceased (Figure 4). Figure 5 presents data in terms of the numbers of crabs collected in separate 4 h counting periods at Tilbury from 1994 to 1996. The averaged data confirm the increase in crab numbers continued in 1996. The seasonal occurrence of crabs at Tilbury corroborates the view that crabs are migrating through the estuary. Peak numbers appear at Tilbury in May.

DISCUSSION

The sudden increase in the Thames catchment mitten crab population is a matter of concern. Schellenberg (1928) states that juvenile mitten crabs can migrate ~1000 km while growing to adult size. Furthermore, Adema (1991) notes that *Eriocheir sinensis* has been found 1500 km inland in China, and that in the River Elbe, Germany, crabs have been found 700–780 km upstream as far as Prague in the Czech Republic. This indicates that the whole of the Thames river system is accessible to invasion and dispersal via canal systems (Petit, 1960) linking catchments is a reality. Moreover, the crab is also capable of crossing dry land to enter new river systems. Further population expansion could eventually threaten freshwater habitats and communities including those currently occupied by the native crayfish *Austropotamobius pallipes* (Lereboullet, 1858) which is already under considerable threat from four species of foreign crayfish introduced into British rivers. Two of these, the Turkish crayfish *Astacus leptodactylus* Eschscoltz, 1823 and the European crayfish *A. astacus* (Linnaeus, 1758) have been introduced from Europe, and the other two, the signal crayfish *Pacifastacus leniusculus* (Dana, 1852) and the red swamp crayfish *Procambarus clarkii* (Girard, 1852) from America. Andrews et al. (1982) documented the macrofauna of the Thames Estuary and components of this too could be threatened by the annual migration of mitten crabs.

A further concern is that *E. sinensis* is also a burrower (Panning, 1939) which could threaten unprotected engineering earthworks – and which resulted in the banning of live mitten crab imports (see Horwath, 1989) into California in 1987 and subsequently the whole of the US in 1989.

In the Far East *E. sinensis* is the second intermediate host of the oriental lung fluke, *Paragonimus westermanii* (Kerbert, 1878), and if the crab is eaten uncooked the parasite can infect humans, causing the disease paragonimiasis. However, establishment of this lung disease in Britain is thought unlikely because *P. westermanii* is specific to a primary intermediate host of aquatic snails assigned to the Thiaridae, and the climate in Britain is too cold for members of this gastropod family.

The population of mitten crabs in the Thames Estuary has increased since 1992 from a previously relatively constant background number. The distribution of *E. sinensis* in the Thames catchment now extends from Staines in the west and northwards to Enfield with records from most tributaries east of Staines. This alien species has the potential to upset the balance of the resident ecosystems in the Thames and it may compete with the native crayfish in freshwater. Finally, the annual migration of thousands of crabs could affect the macrofaunal community of the estuary.

Richard Bettany of London Transport is thanked for allowing us to collect *Eriocheir sinensis* from the intake screens at Lots Road power station. This study was supported by the Environment Agency. Opinions expressed in this paper do not necessarily reflect the policies of the Environment Agency.

REFERENCES

Adema, J.P.H.M., 1991. *Krabben van Nederland en Belgie.* [*Crabs from Holland and Belgium.*] Leiden: Nationaal Natuurhistorisch Museum.

Andrews, M.J., Aston, K.F.A., Rickard, D.G. & Steel, J.E.C., 1982. The macrofauna of the Thames Estuary. *The London Naturalist*, **61**, 30–61.

Cohen, A.N. & Carlton, J.T., 1997. Transoceanic transport mechanisms: introduction of the Chinese mitten crab, *Eriocheir sinensis*, to California. *Pacific Science*, **51**, 1–11.

Dana, J.D., 1852. Macroura. *Conspectus Crustaceorum, &c. Conspectus* of the Crustacea of the Exploring Expedition under Capt. C. Wilkes, U.S.N. *Proceedings of the Academy of Natural Sciences of Philadelphia*, **6**, 10–28.

Eschscholtz, F.F., 1823. Descriptio novae Astacorum speciei Rossicae. *Mémoires de la Société Impériale des Naturalistes de Moscou*, **20**, 109–110.

Girard, C., 1852. A revision of the North American Astaci, with observations on their habits and geographical distribution. *Proceedings of the Academy of Natural Sciences of Philadelphia*, **20**, 87–91.

Haahtela, I., 1963. Some new observations and remarks on the occurrence of the Mitten Crab, *Eriocheir sinensis* Milne Edwards (Crustacea, Decapoda), in Finland. *Aquilo Societas Amicorum Naturae Oulensis*, **1**, 9–16.

Harold, C.H.H., 1935. Thirtieth annual report on the results of the chemical and bacteriological examination of the London Waters for the 12 months ending 31 December 1935. *Metropolitan Water Board London*, p. 101.

Horwath, J.L., 1989. Final Rule on importation of injurious wildlife: mitten crabs. *Federal Register: Rules and Regulations*, **54**, 22286–22289.

Ingle, R.W. & Andrews, M.J., 1976. Chinese mitten crab reappears in Britain. *Nature, London*, **263**, 638.

Kerbert, C., 1878. Zur Trematoden-Kenntnis. *Zoologischer Anzeiger, Liepzig*, **1**, 271–273.

Lereboullet, A., 1858. Description de deux nouvelles espèces d'écrevisse de nos rivières. *Mémoires de la Société des Sciences, Agriculture et Arts de Strasbourg*, **5**, 1–11.

Linnaeus, C., 1758. *Systema Naturae per Regna Tria Naturae, Secundum Classes, Ordines Genera, Species, cum Characteribus, Differentiis, Synonymis, Locis*, vol. 1, 10th ed. Holmiae: Laurentii Savii.

Milne Edwards, H., 1854. Notes sur quelques Crustacés nouveaux ou peu connus conservés dans la collection du Muséum d'Histoire Naturelle. *Archives du Muséum d'Histoire Naturelle*, **7**, 145–192.

Nepszy, S.J. & Leach, H.J., 1973. First records of the Chinese mitten crab, *Eriocheir sinensis* (Crustacea: Brachyura) from North America. *Journal of the Fisheries Research Board of Canada*, **30**, 1909–1910.

Panning, A., 1939. The Chinese mitten crab. *Report of the Board of Regents of the Smithsonian Institution (Washington)*, **3508**, 361–375.

Petit, G., 1960. Le crabe chinois est parvenu en Méditerranée. *Vie et Milieu*, **11**, 133–136.

Schellenberg, A., 1928. *Krebstiere oder Crustacea. II. Decapoda, Zehnfüßer. Die Tierwelt Deutschlands und der angrenzenden Meeresteile.* Jena: Verlag Gustav Fischer.

Vigneux, E., Keith, P. & Noël, P., ed., 1993. *Atlas préliminaire des Crustacés Décapodes d'eau douce de France.* Coll. Patrimoines Naturels, **14**, Paris: Secrétariat de la Faune et de la Flore, Laboratoire de Biologie des Invertébrés Marins et Maalacologie Muséum National d'Histoire Naturelle, Conseil Supérieur de la Pêche, Ministère de l'Environment.

Submitted 18 June 1997. Accepted 1 October 1997.

Appendix G

Hudson River
Background and Information

Included here is some background information on the Hudson River, which is the major estuary in New York State. This information has been kindly provided by Quentin Ross, a biologist with the New York Power Authority. The Hudson River is the source of potable water for six municipalities and for New York City during drought emergencies. It is also the cooling water source for six electric generating stations, the largest of which is the Indian Point Nuclear Generating Station. There is no major diversion of water for agricultural uses in the Hudson River watershed and the water storage reservoirs used to regulate flows during the summer lie above the Troy Dam at Troy, New York, which forms the upper limit of the tidal section of this estuary. The impact of mitten crabs on the water intakes in the tidal section of the estuary is the issue of greatest concern to the municipal and industrial users of water from the Hudson River.

The Hudson River is essentially a drowned valley and there are no dikes along the tidal stretch of this estuary. There are railroad embankments along the length of the river between New York City and Albany. However, these are constructed of shot rock and should not be affected by the burrowing activities of mitten crabs.

The dominant vegetation in the shallow water areas in the freshwater section of the estuary is an exotic nuisance species, the water chestnut (Trapa natans). Thus, the potential impact of mitten crabs on the submerged plant community is not a major issue. Except for a gill net fishery for American shad during the spring, there are no commercial fisheries within this estuary. However, the recreational fisheries for striped bass, blue crab, and freshwater game species are very large and the potential impact of mitten crabs on these fisheries is a major concern.

The lower portion of the Hudson River estuary has a detritus-based food web and the major fish species depend upon epibenthic invertebrate populations. The benthic and epibenthic invertebrates are probably the organisms most likely to be affected directly by mitten crabs and the food web in the lower portion of the Hudson River may be especially susceptible to disruption by this nuisance species. The presence of a major food resource, zebra mussels, in the upper portion of the Hudson River estuary increases the concern about an irruption of mitten crabs and a change in the food web in the lower portion of the estuary.

As a practical aside, a large number of mitten crabs would be collected at the cooling water intakes at the electric generating stations if this species went wild in the Hudson River estuary. Disposal could be a problem and some thought ought to be given to this matter.

END

11-3-00